Cable Television

Third Edition

William Grant

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GWG Associates
Schoharie, NY

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for the

Society of Cable Television Engineers

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Preface

This book presents a tutorial introduction to RF broadband transmission systems utilizing both coaxial cables and optical fibers, with particular emphasis on Cable Television applications. We will introduce the reader to terminology, equipment, and system designs along with explanations of the basic principles involved, and the characteristics of coaxial cable and combinations of coaxial cable and optical fibers in transmission systems, largely for distribution of Cable Television services.

Some commonly employed units of measure and formulas are inevitably required, but the mathematics involved in this text are not sophisticated. We have gone to some lengths to explain the terms and formulas as clearly as possible.

A section of this book presents review questions collated to individual Chapters. We have provided the question answers alone for the readers convenience, and the question answers accompanied by a brief explanation of each answer also. The intent is not to provide any certification of competence, or grade readers to a norm or average. The questions and answers as presented here are intended for the individual reader, or students using this text book in seminars or courses, to review portions of the text and then determine their own comprehension and understanding of the material covered.

This is an introductory text for those people with some technical background or training, particularly in transmission, but with no previous experience or exposure with broadband RF coaxial transmission or analog lightwave systems using optical fibers. For those people, technicians or engineers, who are addressing this technology for the first time, the text will establish a foundation of general understanding from which further studies may be more effectively directed.

Introduction

Although the title of this text is Cable Television, the subject matter be defined as radio frequency (RF) transmission over broadband coaxial cables. The comparatively recent introduction of lightwave transmission on optical fibers can really be considered as simply a bandwidth extension of the coaxial technology, a natural modification or improvement of broadband transmission itself. This transmission technology, broadband systems, has found its widest application in Cable Television (CATV) systems, hence the title chosen, but it certainly can and has been effectively employed for other purposes. Perhaps some basic definition would be a logical starting point for our studies.

CATV Defined

Basically, CATV utilizes broadband physical transmission plant to distribute many television signals throughout a community or area. The acronym CATV developed from Community Antenna Television Service, although it may be more commonly recognized today to mean "cable television".

The facilities employed, mainly coaxial cables but increasingly supplemented with optical fibers in hybrid systems, can accommodate practical transmission systems for frequencies up to and above 800 MHz. Even the earliest, simplest coaxial CATV systems could feed standard television receivers connected to then by service-drop cables, much the same way the telephone instrument is connected to the telephone cable through a house drop.

CATV systems usually involve the construction of entirely new transmission facilities (coaxial cables or coaxial/fiber hybrids) throughout the entire service area. These facilities parallel, in many cases, the existing power and telephone conductors and cables that are already in place and in service to serve the community.

CATV Development

The earliest systems (1948-1949) were constructed in small towns or semi-rural areas where off-air television reception was poor or not available at all, due to transmission distances or geographical features such as mountains. The technique was to construct an elaborate antenna array on a high hilltop, or use a high tower structure to derive off-air signals from TV broadcasting stations. These signals were distributed throughout the community or area as RF signals on a coaxial cable distribution system, which ultimately fed the signals to subscriber-owned television receivers.

In 1952 there were approximately 70 such CATV systems serving a total of 14,000 subscribers or households. These early systems were characterized by carrying few channels, 3 at first, then 5, then 12, and in almost every instance, carrying only signals that had been derived by off-air reception of commercial broadcasting stations.

The equipment, cables, and hardware left much to be desired. The picture quality delivered to subscribers was often marginal, and the operational reliability of such systems was rather poor, since re-amplification was required frequently throughout the system, and the necessary amplifiers actually used vacuum tubes. The level of subscriber tolerance to all these shortcomings was remarkably high, reflecting the subscriber interest in and support of service now generally accepted and amply demonstrated. The business failure rate of these highly entrepreneurial ventures was extremely low, indeed there were almost no failures at all.

In these early systems, and in many systems built today, the TV signals are distributed from a single point (the system head end or point of origin) to many, widely distributed service points (subscriber premises). This is technically analogous to a power distribution network, which is essentially one-way transmission from one point (the power generator or power source) to a multiplicity of points, rather than similar to a telephone network which involves two-way transmission from any one of many points to any one of many others, randomly and on demand.

CATV service rate structures were inconsistent and frequently included rather large initial connection charges ($80 to $100 in many cases), and capital funding through conventional sources such as banks was quite difficult during the early development period. Despite the experimental and somewhat amateurish nature of the pioneering efforts, this embryonic industry flourished.

Quite logically, the industry moved into larger communities where the density of potential subscribers offered greater opportunities for profit. These larger, more complex distribution systems demanded better quality cables and equipment and greater transmission capacity.

The intrusion into these larger markets presented new problems. Since the density of population was greater, the broadcast industry has also directed itself to serving these communities. The CATV operator was in a much more hostile or competitive environment. Where it has previously often been a case of "get on the cable or have no television at all", now the potential customer had at least some modicum of off-air television reception with no monthly service charge as an alternative.

Cable systems no longer enjoyed 80 or 90 percent subscription within their service areas. A new definition of cable TV developed, an awareness that perhaps it was really the entertainment business, basically. The industry directed its efforts at offering more channels and a greater selection or variety of programming to attract more subscribers.

There was significant usage of microwave transmission to import distant stations and new microwave common carrier companies evolved, some of then offering service across several states. This invasion of larger communities by the fledgling industry focused much attention on franchising and regulatory aspects.

The Federal Communications Commission (FCC) asserted limited jurisdiction in 1962. Some states also initiated controls under Public Utility Commission structures, but by and large, cable television system regulation remained a matter of local jurisdiction, with towns, cities, townships, etc., granting individual franchise privileges and maintaining approval or regulation of rates.

Throughout the earlier stages of evolution, individual CATV systems were largely constructed and owned by private individuals or relatively small, locally held companies. These were high-risk ventures with little history or track record to reassure investors, and certainly no guarantees of success. Much the same conditions must have faced the pioneers of rural telephone and rural power companies.

However, with the demonstrated profit potential of the larger communities, and the much larger capital investments these required, the advent of multiple system owners called MSO's was inevitable. Larger groups, with better administrative or management capabilities and greater financial resources began to emerge, both through new construction of systems and through acquisitions of existing properties. These parties brought a new level of professionalism to all aspects to the business. Market analysis encouraged the development of totally new sources of television programming for the industry to offer its customers. And new computerized billing and control systems increased efficiency and return on investments.

As equipment and technology improved and revenue bases grew larger, program sources for 20 and 30 channel systems became available. Special premium viewing channels were initiated on an additional optional payment basis, "pay TV" as it was called, which provided yet another source of revenue from the plant investments which were reaching massive proportions. A fortuitous parallel development of satellite transmission with inexpensive access to many new programs and channels, further accelerated these developments.

Today we find well over 7,000 operating CATV systems serving millions of subscribers. Perhaps one out of every two U.S. television households is served by a CATV system, perhaps more, and we have begun to see a major intrusion of CATV services into the larger cities. The CATV industry shows a pattern of steady growth and increasing penetration of markets. This trend amply supports the conclusion that the general public does desire expanded television program variety, and will economically support such services. There seems little reason to doubt that increasing penetration of major metropolitan markets by CATV services in inevitable.

CATV transmission technology has advanced fairly rapidly from vacuum tubes through discrete transistors to its present utilization of integrated circuits.

Parallel progress was made in coaxial cable design itself, along with coupling and tap-off devices. In addition, optical fibers and lightwave transmission has matured and developed as a graceful addition to, or natural extension of, such systems. It is a fair statement that the current state of the art in amplifiers, hardware, lightwave transmission and cables, can produce an adequately reliable, acceptably low-distortion transmission facility at a supportable cost for most CATV applications.

Regulatory Aspects of CATV

The concept of CATV service itself introduced many new non-technical problems, and raised questions like:

Was it a utility?
Was it entitled to utilize a public rights-of-way?
Should it be regulated?
By whom?
To what degree?
Were municipal franchises necessary or legal?

Eventually, some generally accepted pattern of franchising did emerge and the primary regulatory and rate structure controls were assumed by the local governing authority, the village, town, or city itself, which also retained the franchising privilege.

The utility companies were slow in formalizing their relations with the CATV phenomena, and the broadcast industry quickly recognized a potential threat to status quo, and a series of delaying tactics were employed that artificially delayed CATV growth for many years. All this is history now and may be considered the normal evolutionary problems of any new technology.

Today the legal posture of the CATV industry seems clearly established, and its general relationships with utilities have been formalized to a very large extent. As a matter of fact, there is increased interest by existing utilities in CATV service, and in owning and offering such services to the general public who are, of course, their customers for more traditional service.

Franchising authority and rate control seems to rest within the local community. Several states have placed CATV operations within the jurisdiction of their utility commissions, but in most cases, the extent of this regulation has been either somewhat ambiguous or sporadically applied.

The Federal Communications Commission (FCC) assumed jurisdiction around 1962 but largely limited its control to program carriage regulation only, for some time. Later, a service of FCC technical standards was imposed, and some compliance with minimum transmission capacity was made mandatory for new systems in larger communities. The FCC does not, at present, impose any direct licensing regulations, and has not involved itself with any service responsibility to encourage the development of CATV services in rural areas, and has relaxed some of the earlier rules which precluded ownership and operation of CATV systems by telephone companies.

Coaxial Cable Transmission Systems

The construction of an entirely new transmission network (coaxial cable or hybrid fiber/coax plant) throughout a community or area is an extensive and expensive undertaking.

If new services with new revenue potentials can share this investment, or if other, older services might transition to sharing the investment with beneficial impact on cost effectiveness, the entire proposition would be more attractive.

Coaxial wideband transmission systems, coupled with lightwave transmission as they have evolved for CATV services, are inherently capable of multiple service use. Given the spectrum (5 to 800 MHz or so) that such systems make available, we are free to impose few restrictions on modulation techniques or information processing. Since a CATV system employs wideband transmission capability covering its entire service area, additional services need not even address themselves to specialized intermediate amplifiers at all. This is equally true of bi-directional transmission, which can be readily effected by subdividing the spectrum and using wideband amplifiers in the reverse direction of transmission.

In effect then, a coaxial or hybrid CATV system might quite easily provide private access to substantial spectrum for each direction of transmission at each and every subscriber access point within its service area. This capability, and several variations of it, is an actual reality now, and is being provided as a matter of course in every new CATV system constructed today.

Other Utilization of Coaxial Cable Systems

In discussing other potential services, we are thrust somewhat reluctantly into some "blue-sky" areas, but perhaps this is not entirely a bad thing. In considering other services, two basic distinctions may be reasonably made. The first is for services of a relatively narrow-band or "slow-speed" nature that could be provided by existing telephone facilities as well as by a new wideband system. An example of such services might be meter reading, fire and intruder alarms, etc.

The second group might be defined as more readily accomplished or perhaps more probably provided by a broadband system, because of requirements for transmission spectrum presently beyond the capabilities of the telephone plant. These would, of course, include multiple channel video information such as CATV systems must transport, and can logically be extended to include high-speed data transmission as well.

Alarm systems such as fire, intrusion, etc. , seem to offer some promise as a new source of revenues, but there are as yet no really extensive centralized systems of this type in operation on coaxial cable for residence service.

Power management, sometimes referred to as load control, and various metering of gas, water, electricity, etc., have produced a remarkable amount of interest. The development of the actual hardware and the associated central control equipment and software is still very embryonic, however. The technical practicality seems well assured, but the economic practicality is as yet somewhat uncertain.

One possible utilization of these systems may be in automatic billing, which could be a factor in cost reduction if it consolidated the metered billing of such services as gas, water, or in telephone service itself.

Some of the possible services that might be particularly well served by a wide-band system are even more speculative in nature at this time, but these may eventually hold the greatest promise for new revenues. Visual-plus-aural "shop-at-home" services, for example, where the revenue base is quite easily identified and can be directly related to cash-producing local sales. Though an intriguing possibility, it is as yet largely undeveloped.

Subscriber polling or response systems is another interesting possibility. Viewers could respond to a television channel inquiry or discussion, and results could be tabulated almost immediately. The sophistication of responses may be somewhat limited, but this possibility does show some promise for public opinion polling or perhaps even voting.

The evolution of computer technology, the storage, retrieval, and high-speed delivery of vast amounts of information, is having a profound impact on the communications industry. It takes little imagination to relocated a clerical worker or business manager from a desk equipped with a remote computer readout terminal and a telephone, to a similarly equipped desk in a private home. In fact, the heightened awareness and consideration of energy and petroleum problems tends to support this scenario.

Transportation becomes more costly, and large, centralized, under-utilized commercial buildings are energy inefficient. Every working day we transport literally millions of working Mohammeds to the mountain, where many labor at devices which merely provide access to data. Suppose we took the mountains to Mohammeds? Perhaps assembly work or manufacturing processes do not lend themselves to this, but certainly many other functions would.

The possibilities are both extensive and intriguing, and the wideband system, using RF transmission techniques, seems well adapted for many of these. But CATV is still the service with the most extensive history of profitability using this technology. Although we will focus on CATV applications in this text, our objectives are sound basic understanding of the wideband technology such that we will be prepared to apply it effectively to any transmission requirement.

Chapter 1

Coaxial Cable Transmission Systems

As we discuss RF coaxial cable transmission systems we will encounter and use several general terms that need clear definition, and we must be thoroughly familiar with such factors as system bandwidth, transmission capacity, and allocations of spectrum within a system.

Wideband Transmission

We will define wideband transmission systems as systems offering substantial portions of spectrum for private allocation and use as compared, for example, to broadcasting in free space, which uses public spectrum. The private spectrum may be subdivided into sections by utilizing various filters and frequency assignments, and sections so derived may be used for entirely different services. Indeed, sections of the spectrum may be isolated for transmission in different directions through a coaxial cable system, thus providing bi-directional or two-way transmission capability.

Then the term "wideband" does not denote any specific service or services, nor does it identify any particular technique of modulation or of multiplexing several signals. Coaxial cable, fiber optics, and many microwave transmission systems might all be considered wideband facilities under this definition.

CATV Systems

Cable TV service is only one possible utilization of a wideband transmission system that provides for the distribution of many television channels on the same facility, generally coaxial cable plant, to subscribers' television receivers.

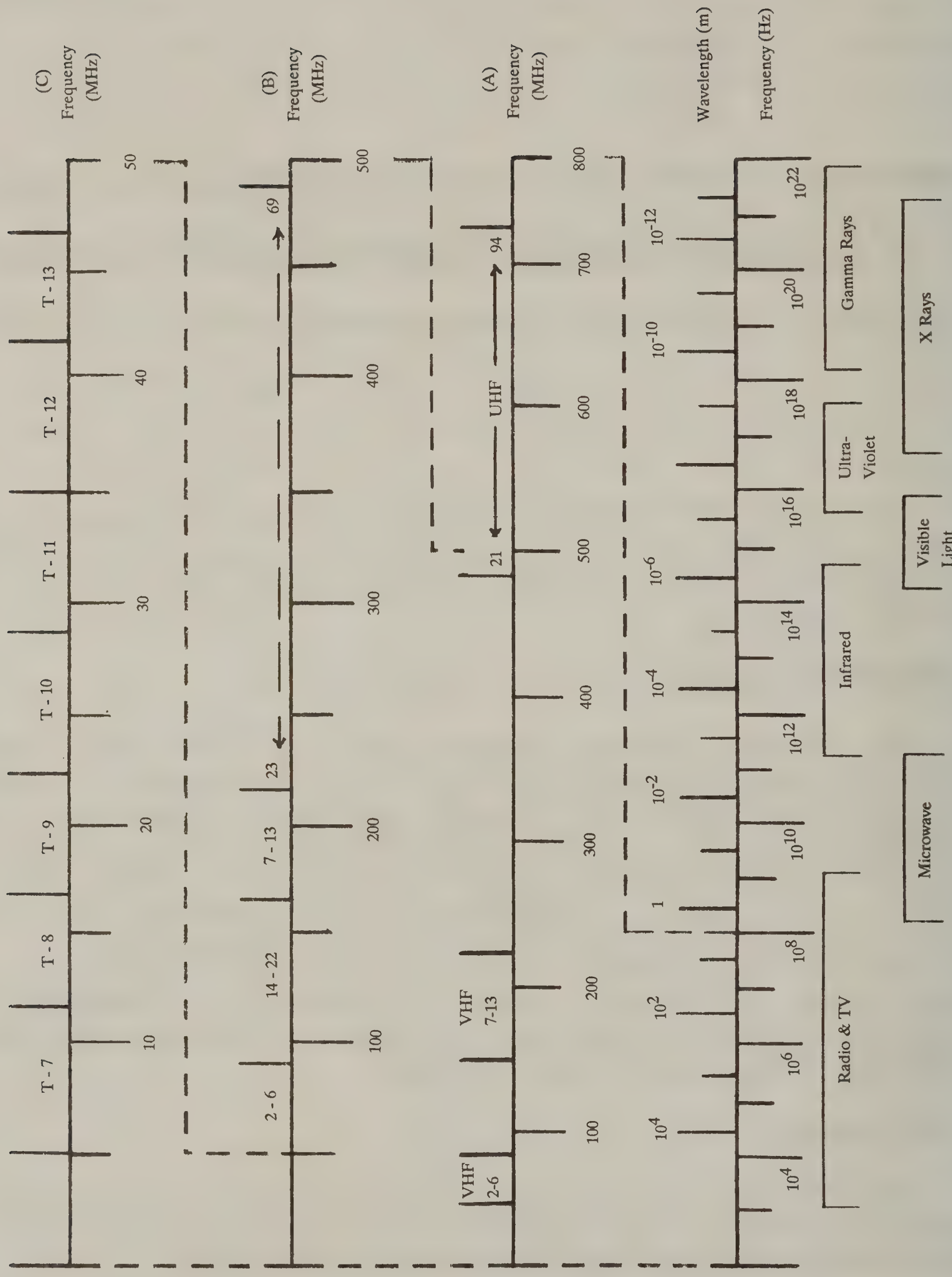

(C) Frequency (MHz)
T - 7
T - 8
T - 9
T - 10
T - 11
T - 12
T - 13
10
20
30
40
50
(B) Frequency (MHz)
2 - 6
14 - 22
7 - 13
23
69
100
200
300
400
500
(A) Frequency (MHz)
VHF 2-6
VHF 7-13
21
UHF
94
100
200
300
400
500
600
700
800
Wavelength (m)
10^4
10^2
1
10^{-2}
10^{-4}
10^{-6}
10^{-10}
10^{-12}
Frequency (Hz)
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
10^{22}
Radio & TV
Microwave
Infrared
Visible Light
Ultra-Violet
X Rays
Gamma Rays

Figure 1-1 Electromagnetic Spectrum

Integrated Wideband Systems

We define an integrated system as one which is simultaneously carrying two or more different or unrelated services. Again the term wideband, as used here, does not denote any specific service or modulation or multiplexing technique; simply that the wideband transmission system provides more than one service. CATV service will most probably be one of the services provided on an integrated system but not necessarily or automatically so in every case. Coaxial wideband systems may be employed entirely for data transmission, or for data plus telephone service only, in Local Area Networks (LANs) or as part of a Wide Area Network (WAN). Integrated systems may or may not require bi-directional or two-way transmission capability.

Electromagnetic Spectrum

The electromagnetic spectrum is shown in Figure 1-1 with all notations in units of frequency (cycles or hertz) or wavelength. The relationship of broadcast television signals to other services is more clearly shown in section A of Figure 1-1 which shows the spectrum up to 800 MHz only, and identifies TV broadcast allocations for both Very High Frequency (VHF) and Ultra High Frequencies (UHF) channels. The spectrum of interest in practical coaxial systems including typical TV channel assignments, is shown in Section B (0 to 500 MHz) and Section C (0 to 50 MHz). Note that as we address the lightwave region of the spectrum, the notation of frequency becomes cumbersome due to the very high frequencies involved. Lightwave frequencies must be designated in terahertz (10^{12} hertz or one million million hertz), which is a difficult figure to work with. It is much more convenient to use wavelength when working with light, and even with some higher microwave ranges also.

Within the electromagnetic spectrum, there are bands of frequencies where waves have common characteristics. These are often referred to in generic terms like audio spectrum, radio spectrum, etc. Radio spectrum, for example, is generally accepted to include the frequencies between 8 kilohertz (KHz) and 300 gigahertz (GHz). Within these generic definitions, waves may be generated or processed using similar techniques or devices. For example, at lower frequencies such as within the audio band, iron core transformers may function quite well, but such devices would be unusable at higher microwave or lightwave frequencies.

Alternating Waves

Radio waves, like sound and light waves, travel in a wavefront. We are speaking of alternating waves, and this term requires clear definition. One complete sequence of values of any electrical wave starting at zero amplitude value, increasing to a maximum value, decreasing to a zero value, decreasing to a minimum amplitude value, and then increasing to a zero value again, as shown in Figure 1-2, is called a complete "cycle."

Since the instantaneous value of the wave is changing, then some time period is required for a complete sequence of changes (a complete cycle) to occur. The time period is universally referenced in seconds. The number of complete cycles that occur in one second can be called "cycles per second," which was the international standard reference for frequency for a very long time. The term cycle PER SECOND has been replaced with the term "hertz," named for the German physicist, Heinrich Hertz. The hertz is identical to and interchangeable with the older term "cycles per second."

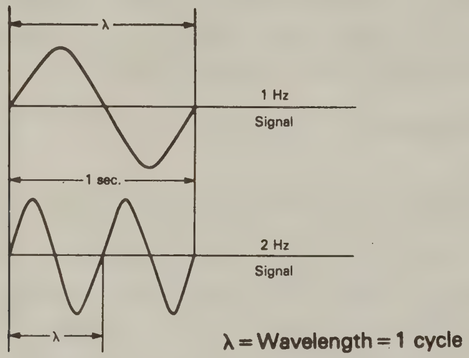


Figure 1-2 Wavelength

Figure 1-2 shows both a 1 Hz and a 2 Hz signal. The 2 Hz signal experiences two complete cycles in the same 1 second time period that the 1 Hz signal experienced only one complete cycle in, and is only half the wavelength of the 1 Hz signal.

In addressing RF transmission over coaxial cables, we will be referencing frequencies up to about 500 megahertz or so. Given the reference of hertz per second, commonly employed terms we will encounter are kilohertz (one thousand hertz), megahertz (one million hertz), and in microwave applications, gigahertz (one billion hertz). The term kilo- is a prefix for 1,000 and may be denoted as 10^3, the term mega- is a prefix for 1,000,000 and may be denoted as 10^6, and the term giga- is a prefix for 1,000,000,000 denoted as 10^9.

Frequency Wavelength Relationship

Electromagnetic waves such as radio waves travel in a vacuum at a speed of 186,280 miles per second, which is the speed of light in a vacuum, also. It is often more convenient to state this velocity of propagation in metric terms, and the figure 300,000,000 meters per second is often used for rough calculations, although 299,793,000 meters per second is more precise. The distance that a wave would travel while experiencing one full cycle of change is called wavelength, and is generally denoted by the Greek letter lambda.

We can state wavelength in units of measure of length (feet or meters) assuming that the velocity of propagation is known. For example, we can easily calculate the wavelength of a 60 hertz wave travelling in space by dividing the velocity of propagation (186,280 miles per second) by the frequency in hertz (60 Hz). Then the wavelength of a 60 Hz signal in space would be 3,104.66 miles.

At very low frequencies such as 60 hertz this may be somewhat academic, but at higher frequencies (shorter wavelengths) it certainly is not. At broadcasting radio frequencies on the order of 1000 kilohertz (1 million hertz or 1 Megahertz) for example, amplitude modulated (AM) radio stations often utilize vertical steel towers as radiating quarter-wavelength antennas. In such cases it is necessary to determine the wavelength in feet or meters to establish the required height of the tower itself.

In the case of a station broadcasting on 1,000 kilohertz, the calculation would be as follows:

Convert the velocity of propagation (186,280 miles per second) to feet per second (983,560,000 feet per second) and divide this figure by the broadcasting frequency in hertz, to establish the wavelength in feet, as

$$\frac{983{,}560{,}000}{1{,}000{,}000} = 983.56 \text{ feet} = \text{one wavelength at } 1{,}000 \text{ KHz}$$

Divide this figure by four to determine the length of a quarter-wavelength, as

$$\frac{983.56}{4} = 245.89 \text{ feet} = 1/4 \text{ wavelength at } 1{,}000\text{KHz}$$

The tower must be 245.89 feet in height if it is to function effectively as a quarter-wave antenna.

Some other example conversion formulas are:

To find wavelength in centimeters given frequency in gigahertz (GHz):

$$\text{Wavelength} = \frac{30}{f\ (\text{GHz})}$$

To find wavelength in meters given frequency in megahertz (MHz):

$$\text{Wavelength} = \frac{300}{f\,(\text{MHz})}$$

In both of these examples, the term for velocity of propagation was related to 300,000,000 meters per second, and if greater precision was required, 299,793,000 could be employed. All electromagnetic waves travel at a slightly different speed in air than in a vacuum, but for practical purposes of our discussion, we will assume the velocity of propagation to be the same for both cases.

Use of the term wavelength as a common reference may be unfamiliar to some readers, but it is by no means new. Radio amateurs and others have always referred to sections of the spectrum as, for example, the 80 meter band (3.5 to 4.0 MHz) or the 10 meter band (28.0 to 29.7 MHz). Even the general public refers to radio frequencies above the commercial broadcast AM band as Shortwave Radio. Being higher in frequency, these are shorter in wavelength. Wavelength is a design factor in many items at higher operational frequencies. The physical dimensions of microwave waveguides, for example, are smaller at higher frequencies, and the element lengths of television antennas reflect the channel for which a particular antenna has been optimized, also.

Transmission Spectrum Allocation

A coaxial cable system can provide 400 MHz and more of spectrum for transmission use. Transmission much above 450 or 500 MHz becomes uneconomic on systems of any significant length due to the coaxial cable losses at higher frequencies. For this reason the transmission of standard Ultra-High Frequency (UHF) television signals (470 to 800 MHz) on broadcast frequencies are precluded, except in smaller installations such as private homes or perhaps motels or small apartment houses. When a CATV system is obliged to transmit such signals, they are converted to lower carrier frequencies which are within the spectrum that such systems can accommodate. Figure 1-1 shows the relationship of standard VHF broadcast television channels 2 through 13, as well as the UHF channels 14 through 88.

It is possible to modulate RF carriers with video information in a variety of ways; by digitizing the information, for example, or by Frequency Modulation (FM) or Amplitude Modulation (AM) techniques. Standard television broadcasting uses AM modulation for the video (picture) information, and FM modulation for the audio (sound), but the video information, although amplitude modulated, does not transmit both sidebands of the carrier. A technique called vestigial sideband transmission, which is not the same as single sideband modulation, is used to limit the transmission spectrum required for each television channel. Since the end devices a CATV system must serve are the subscriber owned television receivers, and since they have been designed to function with standard broadcast signals, the vast majority of CATV systems carry all channels as AM vestigial sideband modulated video and FM modulated audio.

The present state of the art requires 6 MHz of spectrum for each television channel transported, as shown in Figure 1-3, whether the signals are commercial broadcast or on cable. Some portions of a cable transmission systems spectrum may not actually be used in order to avoid awkward frequency assignments, or to protect existing radio telecommunications services which may be external to the coaxial system but which might be interfered with by RF radiation from within the coaxial transmission system.

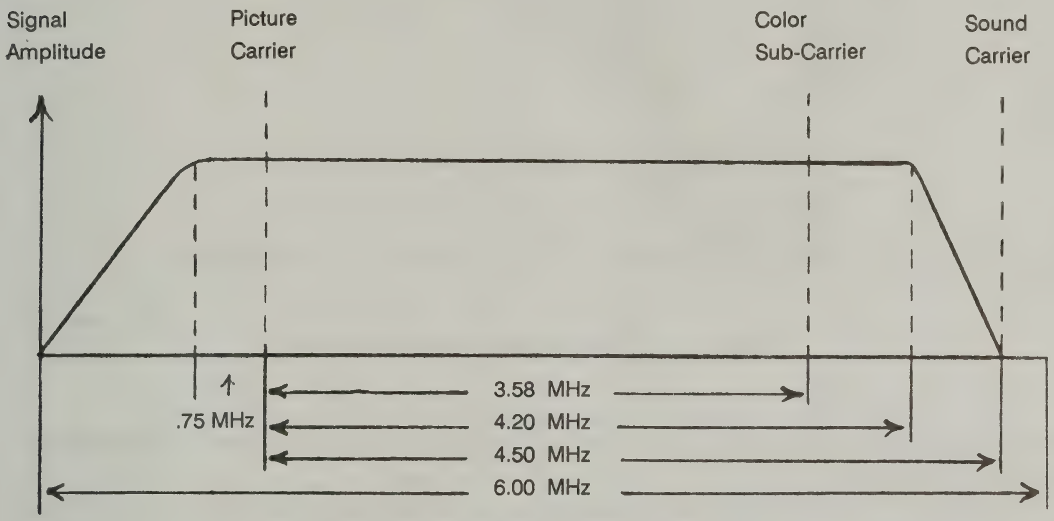


Figure 1-3 TV Channel Spectrum

The practical limitations of a coaxial transmission system are the cable losses at higher frequencies and, as we shall learn as we proceed through the text, the noise and distortion that is introduced to transported information by the amplifiers that must be employed to offset the cable losses. In the earlier systems, these factors imposed an upper transmission frequency limitation of about 220 MHz, and in Figure 1-4 we show the utilization of this spectrum in the earliest 12 channel systems.

Note that the spectrum between 88 and 174 MHz was not utilized in twelve channel systems, but the amplifiers themselves were broadband in nature, and this spectrum was available for use.

The utilization of such systems for twelve channel service was quite logical. Since UHF channels could not be carried on frequency through such systems due to practical limitations, and since all commercially available television receivers tuned channels 2 through 13, then service could be provided up to a 12 channel capacity without the need for any active devices such as converters at the subscriber premises. There actually was a Channel 1 broadcast allocation in the earliest days of commercial TV broadcasting, just below Channel 2, and the range was originally 13 channels (1 through 13), but although Channel 1 was later rescinded for broadcast use by the FCC,

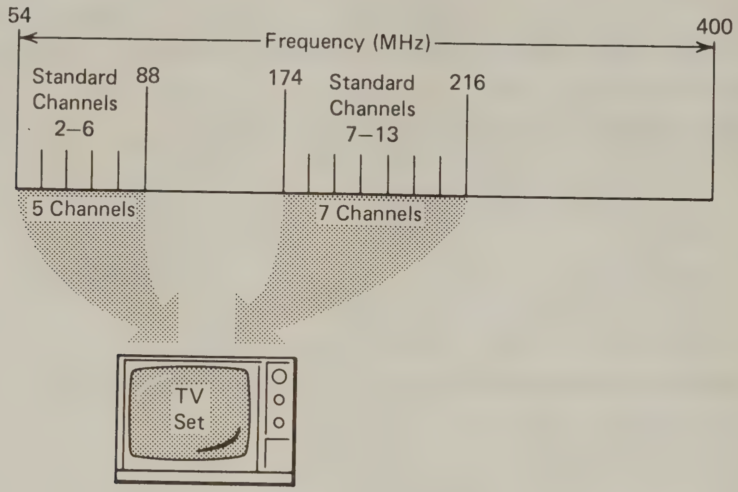


Figure 1-4 Transmission System Spectrum

the nomenclature was in place and was not changed, thus the current assignment of Channels 2 through 13.

In Figure 1-5 we show the subsequent development of CATV service which utilized the spectrum between 88 and 174 MHz by inserting 9 additional television signals into this section. The section was referred to as Mid-Band, since it fell between the low band channels (2 through 6) and the high band channels (7 through 13), and the channel identification used was A through I.

The introduction of more than 12 channels for subscriber service was a significant cost escalation in CATV operations, since at the lowest common denominator, each subscriber receiver, we had to provide an active, power consuming converter so that the subscribers television receiver could detect and display these new signals.

Additional expansion of system transmission capacity was effected by raising the upper frequency response limit of the entire system. An identifiable plateau in this development was 300 MHz, which added Super-Band channels J through W in the spectrum between 216 and 300 MHz, thus permitting 35 channel operations, as shown in Figure 1-6.

A system need not be operated at its full capacity of channels, of course. For example, a 21 channel system can be operated with only 12 standard TV channels (2 through 13) present initially. Many CATV operations transitioned in just this manner, initially providing 21 or 35 channel capacity by design and through construction, but escalating to a higher level of service after demonstrated subscriber support.

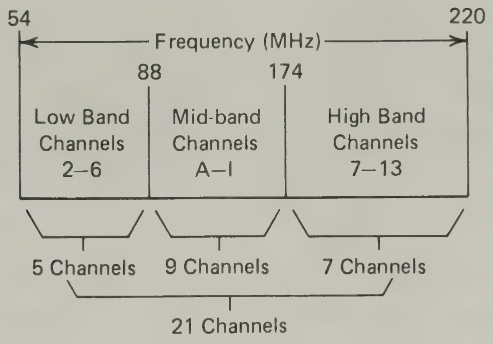

54
220
Frequency (MHz)
88
174
Low Band Channels 2–6
Mid-band Channels A–I
High Band Channels 7–13
5 Channels
9 Channels
7 Channels
21 Channels

Figure 1-5 220 MHz Spectrum Allocation

The transition required adding the new signals to the system, of course, as well as introducing some sophistication and cost at each subscriber location for a converter of some sort.

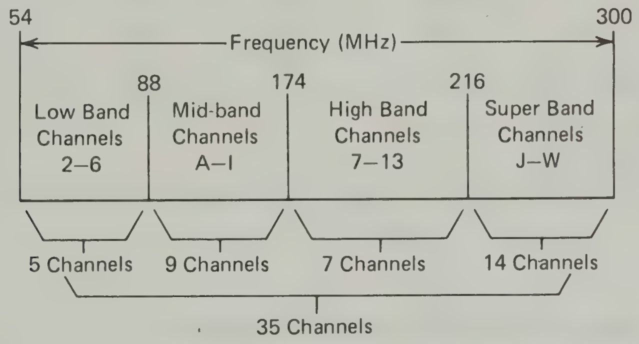

54
300
Frequency (MHz)
88
174
216
Low Band Channels 2–6
Mid-band Channels A–I
High Band Channels 7–13
Super Band Channels J–W
5 Channels
9 Channels
7 Channels
14 Channels
35 Channels

Figure 1-6 300 MHz Spectrum Allocation

In Figure 1-7 we see a system providing spectrum to 400 MHz which could accommodate channels designated AA through QQ, a total of 17 new signals, and raising a 35 channel system capacity to 52 channels. Systems with bandwidth out to 450 MHz and even 500 MHz have been designed and constructed, and in many larger communities dual cables are placed, each fully equipped with amplifiers and subscriber taps. Such systems duplicate the transmission capacity of a single coaxial cable, at a significant cost penalty, of course, and thus we have installations in place today that are capable of 100 channels and more.

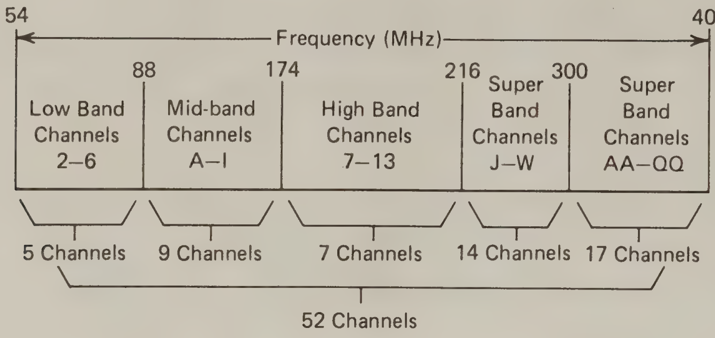

54
400
Frequency (MHz)
88
174
216
300
Low Band Channels 2–6
Mid-band Channels A–I
High Band Channels 7–13
Super Band Channels J–W
Super Band Channels AA–QQ
5 Channels
9 Channels
7 Channels
14 Channels
17 Channels
52 Channels

Figure 1-7 400 MHz Spectrum Allocation

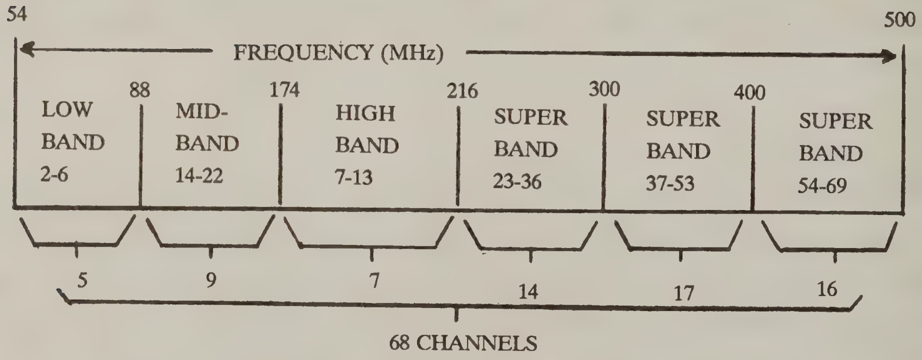

54
500
FREQUENCY (MHz)
88
174
216
300
400
LOW BAND 2-6
MID-BAND 14-22
HIGH BAND 7-13
SUPER BAND 23-36
SUPER BAND 37-53
SUPER BAND 54-69
5
9
7
14
17
16
68 CHANNELS

Figure 1-8 500 MHz Spectrum Allocation

Quite obviously the extension of transmission bandwidth imposes much more severe performance specifications on all system devices including amplifiers and taps. When the transmission spectrum is increased it is more difficult to design and manufacture devices that present acceptable frequency response characteristics, as well as produce amplifiers that can handle the additional power of a multiplicity of signals while still introducing acceptable levels of distortion.

In Figure 1-8 we show a system providing spectrum to 500 MHz. When system bandwidth was extended out to 300 MHz, the industry chose to designate the added channels alphabetically as A to I, which are the Mid-Band channels in the drawings we have presented. Later, when spectrum extended to 300 MHz, the designation used was J through W, and these were called Super-Band channels.

Still another extension evolved out to 400 MHz and the designations AA through QQ came into usage. As we see in Figure 1-8 the additional extension to 500 MHz initiated the substitution of numerical channel designations throughout the entire cable spectrum. In Figure 1-8 this distinction is made by showing both the alphabetical and the numerical designations, where both might be applicable.

Subscriber Converter

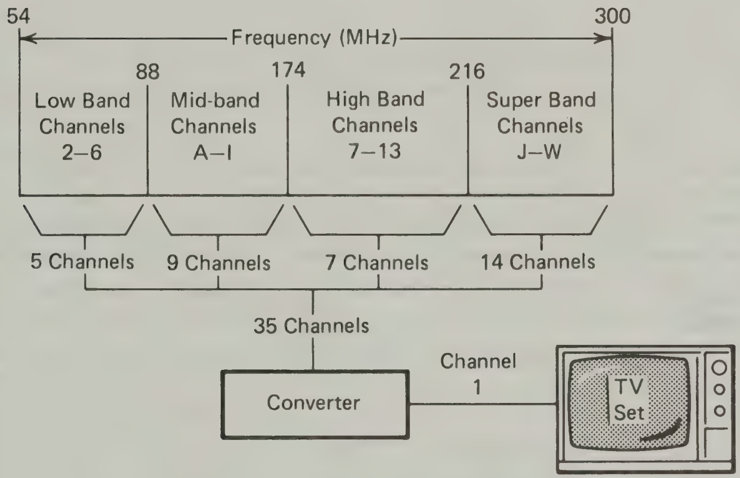

54
Frequency (MHz)
300
88
174
216
Low Band Channels 2–6
Mid-band Channels A–I
High Band Channels 7–13
Super Band Channels J–W
5 Channels
9 Channels
7 Channels
14 Channels
35 Channels
Converter
Channel 1
TV Set

Figure 1-9 Subscriber Converter

Note the use of a converter at the subscriber's premises shown in Figure 1-9 for a 35 channel system. This unit is required, in one form or another, whenever the number of channels presented to the television set exceeds 12. The "magic" number 12 is established by the capacity of the standard television receiver to tune 12 VHF channels without any special accommodation or frequency translation. The addition of a set converter to a CATV system is a very significant cost plateau, since one converter is required for each and every TV receiver served. There are several types of converters available which will be discussed later.

If we expand the system transmission bandwidth by raising the high-frequency limitation, we quite obviously increase the system transmission capability, but we also increase the system cost for reasons that will be made clear later. If the system is constructed for a higher channel capacity than it is initially operated at to expand service at a later date, the addition of converters at subscriber receivers' is all that is required, and the transmission system itself would require no major modifications or changes.

Two-way Transmission

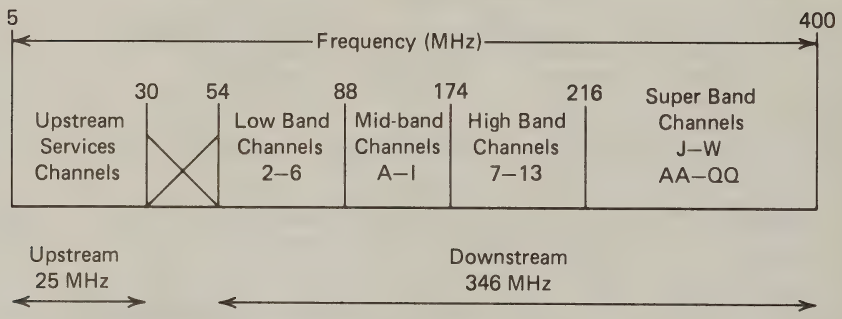

5
400
Frequency (MHz)
30
54
88
174
216
Upstream Services Channels
Low Band Channels 2–6
Mid-band Channels A–I
High Band Channels 7–13
Super Band Channels J–W AA–QQ
Upstream 25 MHz
Downstream 346 MHz

Figure 1-10 Two-way Spectrum Allocation

Figure 1-10 shows the lower end of the spectrum expanded so that the entire bandwidth available is now 5 to 400 MHz. For two-way service this additional spectrum might be allocated as shown, although other separation filters are available for other allocation schemes (see Figure 1-11).

The scheme shown in Figure 1-10 is perhaps the most common. Note that it does not preempt the use of any of the standard VHF TV channels (2 through 13). The spectrum between 30 and 50 MHz has been sacrificed to accommodate the crossover or two-way filters. Because the spectrum has been separated or isolated below standard broadcast Channel 2, the configuration shown in Figure 1-10 is called a Sub-Split system. An alternative configuration, called a Mid-Split system because it separates spectrum between the high band and low band channels, is shown in Figure 1-11.

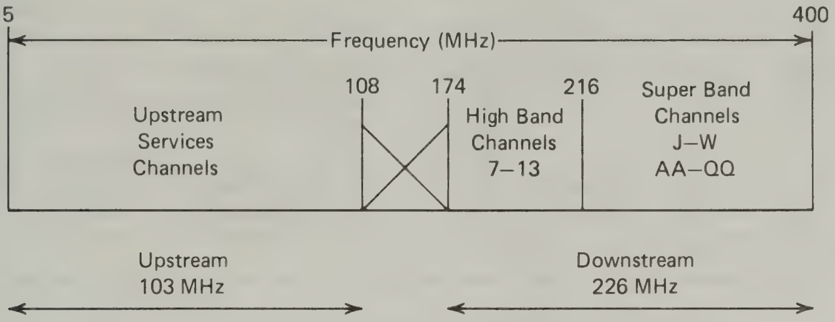


Figure 1-11 Alternative Two-way Allocation

Subscriber Terminals

If we combine an inherently wideband facility such as a coaxial cable with other equipments (including amplifiers) that have a complementary transmission bandwidth, we can construct transmission systems with 450 MHz or greater bandwidth. As we have seen, we can isolate this spectrum in various ways to accommodate different directions of transmission, thus producing two-way systems. If this spectrum is to handle a number of different services, then we will have to separate the spectrum for the different services at each subscriber terminal.

In Figure 1-12 we show how this might be accomplished for a Sub-Split system without actually defining any of the other services specifically. Note the terminology "upstream" and "downstream" in Figures 1-10 and 1-11. We use downstream to denote the transmission direction that the many television channels use from the system head end or point of origin out to the subscribers' premises, with upstream being transmissions originating at the subscriber terminals or elsewhere out in the system.

Coaxial Cable Transmission

In designing coaxial cable systems for whatever purpose or service, it is self-evident that the coaxial cable itself will introduce transmission loss. It may very well introduce several other problems also, but it will certainly introduce loss.

To produce systems of any significant usable length, the periodic insertion of gain through the use of amplifying devices is required. And whenever the cable route is divided or split to serve radial legs or side leads, or whenever the system must be tapped to provide service to subscribers, the devices used introduce additional transmission loss into the system.

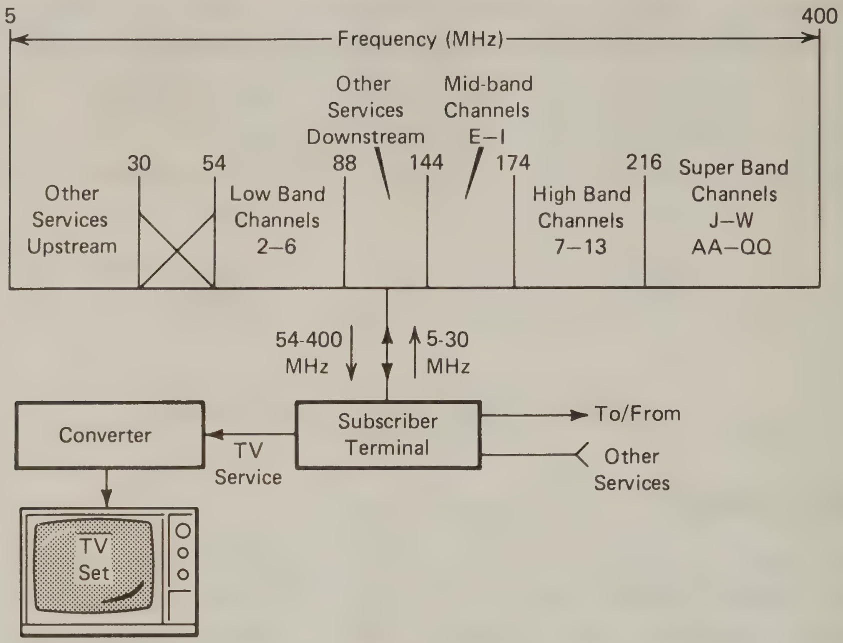

5
400
Frequency (MHz)
Other Services Downstream
Mid-band Channels E–I
30
54
88
144
174
216
Other Services Upstream
Low Band Channels 2–6
High Band Channels 7–13
Super Band Channels J–W AA–QQ
54-400 MHz
5-30 MHz
Converter
TV Service
Subscriber Terminal
To/From
Other Services
TV Set

Figure 1-12 Subscriber Terminal Unit

A coaxial cable system might be considered as a series of small sections in tandem. Each section consists of the interconnecting coaxial cable, any taps or splitters inserted into it, and an amplifier. Each amplifier is intended to precisely overcome all transmission losses incurred in that section of the plant. In effect, a section is operated at unity gain, and all loss is followed by an equivalent gain. Any system frequency response distortion introduced by component parts (be they cable, taps, amplifiers, etc.) within a section is, ideally, also corrected by equalization within that section and its amplifier.

Of course, different types and sizes of coaxial cable introduce different transmission loss, and contribute different costs. Two-way hardware is now standard throughout the CATV industry and is available from almost all suppliers of equipment. The designs of equipment are such that an initial installation of one-way equipment can be upgraded with plug-in ancillary equipment and filters to provide the two-way capability at any time.

Summary

In the development of coaxial cable systems we will be primarily concerned with the following major factors:

1. Transmission loss
2. Frequency response
3. Amplifier gain
4. Noise
5. Intermodulation distortion
6. Costs

We must thoroughly understand the nature and interrelationships of all these factors, and we will separately address each of these as we progress through the text.

Chapter 2

Understanding Decibels

In a cable television system it is necessary to be able to design, construct, and operate plant over a long period of time, while maintaining relatively constant signal levels and signal quality at all points in the system. In order to do this, standard units of measurement have been adopted, and we must be thoroughly familiar with these units and completely comfortable with their usage.

The two basic factors involved in RF transmission over coaxial cables are transmission losses, as introduced by the cable itself, and such passive devices as splitters, taps, etc., and transmission gain, as introduced by amplifiers.

It is possible to do all system engineering and maintenance using actual signal power levels, but this would be very awkward. For example, consider a single TV signal leaving the system head end at a level of 13.3 microwatts which is, as we shall come to understand, +30 dBmV. A micro-watt is one millionth of a watt.

If we launch this signal into a coaxial cable of any significant length, the signal will propagate through the cable and we will recover some of the signal but not all, at the distant cable end. We will not recover all the signal energy because the cable introduces transmission loss.

It is possible to calculate the amount of signal power that would be lost in passing through the cable, and deducting this from the cable input signal power level, we can determine how much signal power we would recover at the cable end. We can also calculate the transmission losses for passive devices such as splitters and taps, etc., in a similar manner. Thus we could establish the power level of the signal at any given point in the system.

This method would work, and is technically sound, but it would require a great many calculations and would introduce the possibility of many errors. It would also be quite tedious and time consuming.

A more convenient method would employ units of measure that would be equally applicable to both transmission losses or gains, and to signal levels as well.

Then the development of signal level at any point in a system would be a simple matter of addition and subtraction. This is exactly what has been done, and the basic concept involved is to deal with ratios of power, rather than with discrete power levels.

Ratios

A ratio, by definition, is the relation in degree or number between two similar things. The ratio between a ten pound weight and a one pound weight for example, is 10. Not ten pounds, but a ratio of 10 to 1, since the ten pound weight is 10 times heavier than the one pound weight. The ratio between a one hundred pound weight and a ten pound weight is also 10 to 1, since the one hundred pound weight is ten times heavier than the ten pound weight.

Note that when we are dealing in ratios we cannot correctly express a specific weight as a ratio. In our example above, a ratio of 10 was equally accurate and applicable to both examples even though the two different weights compared were different for each example. The ratio is a very useful figure, as we shall see, and we will employ it extensively in cable television technology.

In RF transmission over coaxial cables (CATV technology), we are concerned with signal levels that can be denoted as levels of power. You will recall that our head end signal which was launched into a coaxial cable in the earlier example was defined as a power level of 13.3 microwatts. We recognize that at the far end of the long cable we will recover a lower power level signal due to the transmission loss of the cable.

Then we are considering two different power levels, the higher level cable input signal, and the lower level cable output signal. We could, if it was useful to do so, denote the ratio between these two levels but we will require some term.

The Bel

A basic term used to denote the power ratio of two levels of power, voltage, current, or sound intensity is the Bel, named after Alexander Graham Bell. Just as in our earlier example with weights, the Bel cannot be used to denote any specific level but only the ratio between two levels.

By definition, one Bel will denote a ratio of 10 to 1, but always between two discrete power levels. Let us be quite certain we understand this point. If we had a signal input to a device of 10 watts (a watt is a unit of measure of power), and an output signal from that device of 100 watts, the ratio between these two power levels would be 10 to 1. Since the output level is greater than the input level the device would be said to have gain, and the gain could be denoted as +1 Bel, since the ratio between the levels was 10 to 1.

This would be equally true of another device whose input was 100 watts and whose output was 1,000 watts. Since the ratio between the two power levels is 10 to 1, this device would also have a gain of +1 Bel.

A Bel may be a negative or a positive value, and thus it can denote either gain or loss. For example, if the power input to a section of cable were 100 watts and the signal recovered at the distant end of the cable were 10 watts, the relationship between the two power levels would be 10 to 1. Since the input is greater than the output the cable would be said to have loss, and the loss could be denoted as -1 Bel, since the ratio between the two levels was 10.

In another example, if the input level to a device was 10 watts and the output from that device was 1 watt, the ratio between the two is 10 to 1 but would be expressed as a negative number, -1 Bel. With 1,000 watts input and 100 watts output, the loss would also be expressed as a negative ratio of -1 Bel.

The Bel is a perfectly respectable, technically acceptable unit of ratio measurement but was found to be awkwardly large. To avoid the necessity for working with decimal values of the Bel, the decibel was adopted.

The Decibel

The decibel, denoted dB (note lower case d and capital B), is one tenth of a Bel. Thus 10 dB = 1 Bel, 20 dB = 2 Bels, and 30 dB = 3 Bels, etc. In all respects, the decibel functions exactly the same as the Bel. It may be negative or positive to denote gain or loss but it cannot, of itself, be used to denote any specific power level, only the ratio between two discrete power levels. We use the decibel exclusively and extensively in the cable television business and we also find it employed extensively in other transmission disciplines. The relationship between power ratios and both Bels and decibels can be seen in Table 2-A. Both Bels and decibels are logarithmic.

TABLE 2-A Bels and Decibels

Power Ratio	Value in Bels	Value in decibels
1 to 1	0	0
2 to 1	.3	3
10 to 1	1	10
100 to 1	2	20
1,000 to 1	3	30
10,000 to 1	4	40

Logarithms

The logarithm (log) of a number is defined as the exponent to the base 10 that produces that same number. For example, the log of N is 4, if $10^4 = N$. Note that in this expression 4 is the exponent of 10.

Example: $N = 1{,}000$

or $N = 10^3$
or $N = 10 \times 10 \times 10$
or $N = 100 \times 10$
or $N = 1{,}000$

Since $1{,}000 = 10^3$ then 3 is the logarithm of 1,000.

Example: What is the logarithm of 10,000?

$N = 10{,}000$

or $N = 10^4$
or $N = 10 \times 10 \times 10 \times 10$
or $N = 100 \times 10 \times 10$
or $N = 1{,}000 \times 10$
or $N = 10{,}000$

Since $10{,}000 = 10^4$ then 4 is the logarithm of 10,000.

These previous examples all used multiples of ten for simplicity, but every number has a logarithm. Some random examples are:

Number	Logarithm
2	.301
3	.477
7	.845
10	1.000
14	1.146
100	2.000
283	2.452

Note that for numbers below 10 the logarithm is a decimal number less than 1. For numbers between 10 and 100, the logarithm will always be 1 plus some decimal numbers, or 1.xxx. For numbers between 100 and 1,000 the logarithm will always be 2 plus some decimal numbers, or 2.xxx. The logarithm for any number can be found in a Log Table in many technical books or taken directly off a slide rule or a calculator.

Power Ratios

There is a formula to determine the ratio in decibels between two power levels.

$$dB = 10 \log \frac{P_2}{P_1}$$

Example: What is the power ratio between a 400 hp engine and a 200 hp engine?

$$dB = 10 \log \frac{P_2}{P_1}$$

$$= 10 \log \frac{400}{200}$$

$$= 10 \log 2 \qquad \text{(log of 2 is .3)}$$

$$= 10 \times .3$$

$$= 3 \text{ dB}$$

Example: Given an input to a device of 100 watts, and an output from the device of 1,000 watts, what is the power ratio in dB?

$$dB = 10 \log \frac{P_1}{P_2}$$

$$= 10 \log \frac{1{,}000}{100}$$

$$= 10 \log 10 \qquad \text{(log of 10 is 1)}$$

$$= 10 \times 1$$

$$= +10 \text{ dB}$$

This agrees with the ratio given in both Tables 2-A and 2-B for a power ratio of 10 to 1.

Table 2-B Bels and Decibels

Power Ratio	10 as a Factor	Value in Bels	Value in decibels
1 to 1	10^0	0	0
2 to 1	$10^{.3}$	.3	3
10 to 1	10^1	1	10
100 to 1	10^2	2	20
1,000 to 1	10^3	3	30
10,000 to 1	10^4	4	40

As we stated earlier, dB can be positive or negative, denoting either loss or gain. Using the power ratio formula, let us do a few examples to familiarize ourselves with the process involved.

Example: Amplifier input = 2 watts
Amplifier output = 20 watts
What is amplifier gain in dB?

$$dB = 10 \log \frac{P_2}{P_1}$$

$$= 10 \log \frac{20}{2}$$

$$= 10 \log 1 \qquad \text{(log of 10 is 1)}$$

$$= 10 \times 1$$

$$= +10 \text{ dB}$$

Example: Cable input = 20 watts
Cable Output = 2 watts
What is cable loss in dB?

$$dB = 10 \log \frac{P_2}{P_1}$$

$$= 10 \log \frac{2}{20}$$

$$= 10 \log \frac{1}{10}$$

$$= -10 \log 10 \quad \text{(log of 10 is 1)}$$

$$= -10 \times 1$$

$$= -10 \text{ dB}$$

Example: Splitter Input = 40 watts
Splitter Output = 20 watts
What is splitting loss in dB?

Note: By definition, a splitter divides the input power equally between two outputs.

$$\text{dB} = 10 \log \frac{P_2}{P_1}$$

$$= 10 \log \frac{20}{40}$$

$$= 10 \log \frac{1}{2}$$

$$= -10 \log 2 \quad \text{(log of 2 is .3)}$$

$$= -10 \times .3$$

$$= -3 \text{ dB}$$

We can see that the power ratio between any two power levels can be easily determined. It will be very convenient if the more common power ratios are simply memorized however, and a quick glance at Table 2-B should help accomplish this.

A power ratio of 2 to 1 is 3 dB. It follows that twice as much power, a 2 to 1 ratio, would be +3 dB, and half as much power, a 1 to 2 ratio, would be -3 dB. A 10 to 1 ratio or ten times as much power, would be +10 dB. It follows that one tenth as much power (a 1 to 10 ratio) would be -10 dB. A 100 to 1 ratio would be +20 dB if it were gain, and one one hundredth as much power would be -20 dB.

How does this relate to discrete signal levels?

The Decibel-millivolt (dBmV)

A reference power level has been established and is called the decibel-millivolt, written as dBmV (note capital B and V). This unit is assigned a specific value.

0 dBmV = 1 millivolt measured across 75 ohms.

Note the reference to 75 ohms. By definition, one millivolt measured across any impedance value other than 75 ohms does not represent a power level of 0 dBmV. In the cable television business we rarely encounter impedances other than 75 ohms, including the coaxial cable itself which has a characteristic impedance of 75 ohms. We denote signal levels in dBmV almost exclusively in the cable television business.

One millivolt is one one thousandth of a volt, and 0 dBmV could also be written as:

0 dBmV = .001 volts measured across 75 ohms

or

0 dBmV = 10^{-3} volts measured across 75 ohms

Using Ohm's Law, we can calculate the absolute power level that 0 dBmV represents as follows:

$$\text{Power (P)} = \frac{\text{Voltage squared}}{\text{Impedance}} \quad \text{or} \quad P = \frac{E^2}{R}$$

By definition the voltage was given to be .001 volts, and the impedance was specified to be 75 ohms, thus

$$P = \frac{.001^2}{75}$$

$$P = \frac{.000001}{75}$$

$$0 \text{ dBmV} = .0133 \text{ microwatts}$$

or

$$0 \text{ dBmV} = .0133 \times 10^{-6} \text{ watts}$$

All of the above are correct and given a reference power level (dBmV), we can now establish a discrete power level for any signal, at any point in a system, if we are also given a power ratio.

Applying dBmV

Suppose we had measured a power level of .0133 watts at some point in a system. Note this is not the same level as .0133 microwatts, it is substantially more power than that. We would like to convert this absolute power measurement (.0133 watts) to dBmV to facilitate using the result in system calculations. We can apply the formula for power ratio as follows:

$$dB = 10 \log \frac{P_2}{P_1}$$

Perhaps we can identify the power levels more clearly as

$$dB = 10 \log \frac{P \text{ (measured)}}{P \text{ (reference)}}$$

In our problem, the measured power level was given to be .0133 watts, so we can simply insert that value into the above formula as the measured power value. The reference power level is taken from the specified value of 0 dBmV, and this was determined earlier by calculation to be $.0133 \times 10^{-6}$ watts, so we can insert this value into the above formula also as

$$dB = 10 \log \frac{.0133}{.0133 \times 10^{-6}}$$

$$= 10 \log 10^6 \quad \text{(log of } 10^6 \text{ is 6)}$$

$$= 10 \times 6$$

$$= +60 \text{ dBmV}$$

Then a measured power level of .0133 watts represents a power level of +60 dBmV or, .0133 watts referenced to 0 dBmV is +60 dBmV.

Other Power References

There are other power reference levels used in other engineering disciplines and they should not be confused with dBmV. A reference frequently used in microwave and lightwave engineering, and in telephone transmission work also, is 0 dBm. By definition 0 dBm is a power level of one one thousandth of a watt or 1 milliwatt. Note that this definition is less complex than that for dBmV in that no impedance value is specified. This reference, 0 dBm, always equals 1 milliwatt regardless of the impedance of the circuit or device where this level is specified. The reference 0 dBmV will only equal $.0133 \times 10^{-6}$ watts if the impedance at which this level is specified is 75 ohms.

Since the absolute power level of 0 dBmV is known to be $.0133 \times 10^{-6}$ watts, and 0 dBm is known to be .001 watts, we can determine the value of 0 dBm in dBmV as follows:

$$\text{Formula: dBmV} = 10 \log \frac{P_2}{P_1}$$

$$= 10 \log \frac{.001}{.0133 \times 10^{-6}}$$

$$= 10 \log (7.5188 \times 10^4)$$

$$= 10 \times 4.876$$

$$= +48.76 \text{ dBmV}$$

We stated earlier that 1 horsepower (hp) equals 746 watts. Since any discrete power level given in units of power measurement can be converted to dBmV, which is a unit of power measurement, it might be instructional to determine the value of 1 horsepower in dBmV.

$$\textbf{Formula: } \text{dBmV} = 10 \log \frac{P_2}{P_1}$$

$$= 10 \log \frac{746}{.0133 \times 10^{-6}}$$

$$= 10 \log (5.609 \times 10^{10})$$

$$= 10 \times 10.749$$

$$= +107 \text{ dBmV}$$

Using dB and dBmV

Given any discrete signal level in dBmV, which would be an absolute power level since it is a power ratio referenced to an absolute power level ($.0133 \times 10^{-6}$ watts), we can conveniently work directly with power gain or loss ratios that are given in decibels (dBs).

Example 1: In Figure 2-1 we show a small section of a system including two amplifiers and an indeterminate length of interconnecting coaxial cable. The transmission loss of the cable is given to be 22 dB, the ratio between the cable power input and the cable power output.

The input signal level to the first amplifier is given to be +12 dBmV, which is a specific power level. The amplifier is specified to have a gain of 22 dB, the ratio between the amplifier input power and the amplifier output power. A 22 dB gain amplifier could have a +10 dBmV input and produce a +32 dBmV output, or it could have a +20 dBmV input and produce a +42 dBmV output, but in both cases it would be providing 22 dB of gain.

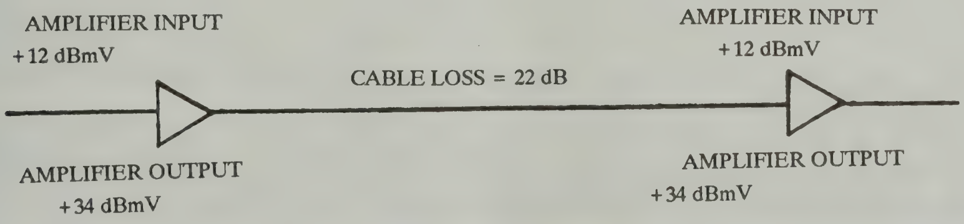


Figure 2-1 Applying Decibels

Given an amplifier input of +12 dBmV and an amplifier gain of 22 dB, we establish the amplifier output level to be +34 dBmV by simple addition of the two figures. Given a cable loss figure of 22 dB, we simply subtract this figure from the first amplifier output level of +34 dBmV, and determine that the input level to the second amplifier is +12 dBmV. Again, with 22 dB of gain in this second amplifier and an input of +12 dBmV, the output level is established as +34 dBmV by simple addition. This example clearly demonstrates the facility of using dB and dBmV instead of calculating discrete signal levels in conventional units of power measurement such as milliwatts or microwatts, etc. Since any value of dBmV represents a discrete power level, we have not sacrificed precision by this process, but we have gained a very simple and workable method.

Example 2: In Figure 2-2 we show a power splitter with an input signal level of +37.5 dBmV. By definition, a splitter is a device that divides its input power equally between two output ports. In our earlier discussion we demonstrated that 3 dB would represent a 2 to 1 power ratio. Since a splitter divides its input equally across two outputs, it follows that only half the input power would be available at either of the output ports. Then the theoretical power loss for a signal passing through a splitter would be -3 dB, which is half of the input power.

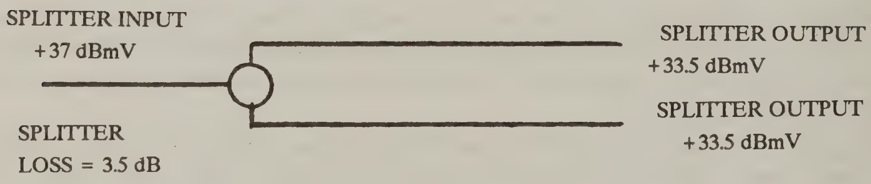


Figure 2-2 Cable Splitter

In actual reality, practical splitters have some intrinsic losses above and beyond the theoretical 3 dB loss due to the inefficiency of the devices, the impedance matching required at input and output ports, etc. Devices on the market today might be specified to present 3.5 dB of transmission loss, rather than the theoretical 3 dB, and this figure is arbitrarily selected here for instructional purposes.

Using a 3.5 dB insertion loss figure, the splitter output levels can be easily determined by simply subtracting 3.5 dB from the stated input signal level of +37.5 dBmV, establishing the signal level at both output ports to be +34.0 dBmV.

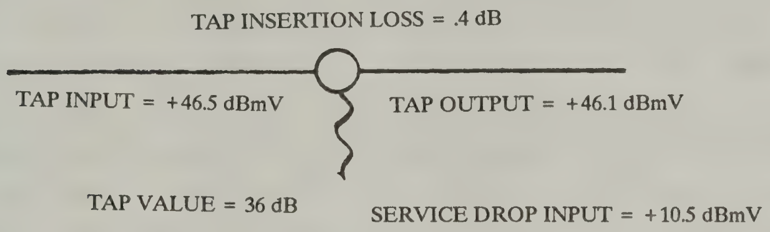


Figure 2-3 Subscriber Tap

Example 3: Figure 2-3 shows a subscriber tap device inserted into a coaxial cable system. The input signal level to the device is given to be +46.5 dBmV. The tap is shown to introduce .4 dB of attenuation or loss to signals passing through the tap along the main cable, and the tap value is given to be 36 dB, which simply means that the tap port output to the service drop will be 36 dB lower in level than the tap input signal was.

We are asked to determine the signal level at the input to the subscriber service drop cable and at the tap output port that feeds the extension of the main cable.

Given a tap input level of +46.5 dBmV, by simply subtracting the .4 dB insertion loss which was specified for the tap, the tap output to the main cable is established to be +46.1 dBmV. If the tap loss to the service drop is 36 dB, as it was given to be, and the tap input signal level was +46.5 dBmV, simple subtraction establishes the service drop input level to be +10.5 dBmV from 46.5 - 36 = +10.5 dBmV.

Summary on dB and dBmV

As we have shown, any time it becomes necessary or desirable, we can easily determine the signal level in units of power (watts, milliwatts, microwatts, etc.) directly from the value in dBmV, either by calculation or from the equivalency tables in reference books that give the values directly. It is important to remember that decibels (dBs) only identify a ratio between two power levels, and cannot be used to denote specific or discrete signal levels.

Decibel-millivolts (dBmVs) do denote specific and discrete signal levels. Both terms are related however, and system calculations can use both in simple addition and subtraction, producing a specific signal level in dBmV for any point in a system whenever necessary. The level, in dBmV, can be converted to power units at any time.

In day to day practice we sometimes become a bit careless in the use of these two terms. It is not unusual, for example, to hear people referencing an amplifier input level as +12 dB, or the signal level at a subscriber's television receiver as +3 dB, but such usage is technically incorrect and somewhat unprofessional as well. We should try to use these, and all other technical terms, correctly.

Ohm's law

There are other calculations that we will be required to perform in the design or operation of catv systems that deal with voltage, current, resistance, and power. The basic law governing the relationship between these factors is Ohm's law, named after the german physicist, George Simon Ohm. Ohm's law simply stated is based upon the fact that a difference of potential (a voltage) of one volt, applied across a resistance of one ohm, will produce a flow of one ampere of current through the device or network.

This may be denoted as

$$E = I \times R \quad \text{and} \quad P = E \times I$$

where: E = voltage in volts
I = current in amperes
R = impedance or resistance in ohms
P = power in watts

Variations on the basic formulas allow us to determine any single factor if the other two are known:

$$E = I \times R \quad \text{or} \quad I = \frac{E}{R} \quad \text{or} \quad R = \frac{E}{I}$$

We can substitute in the power formula as follows:

$$P = E \times I \quad \text{or} \quad P = E \times \frac{E}{R} \quad \text{or} \quad P = \frac{E^2}{R}$$

and

$$P = E \times I \quad \text{or} \quad P = (I \times R) \times I \quad \text{or} \quad P = I^2 \times R$$

When we discuss powering coaxial system amplifiers over the coaxial cable itself, as we will later in the text, we shall have to apply basic Ohm's law, but it also has some relevance to our present discussion of dB and dBmV.

Voltage Measurements in Coaxial Systems

Although all of our discussion has centered on signal level as values of power, it may be more convenient at times to make voltage measurements in working systems, rather than actual power measurements. We can easily convert voltage measurements to values of dBmV also. Since all measurements in a coaxial cable system will normally be made across a 75 ohm impedance (cables, amplifiers, taps, etc., all have a characteristic impedance of 75 ohms) the calculation is quite simple.

$$\text{dBmV} = 20 \log \frac{E \text{ (voltage measured)}}{E \text{ (voltage reference)}}$$

Since our earlier power calculations used the term "10 log," the use of the term "20 log" may be confusing, but there is a simple explanation.

Ohm's law states that $P = E \times I$ and substituting

$\frac{E}{R}$ for the factor I we develop $P = \frac{E^2}{R}$

The power formula stated: $\text{dB} = 10 \log \frac{P_2}{P_1}$

If we substitute the power statement $\frac{E^2}{R}$ in the above we have

$$\text{dB} = 10 \log \frac{\frac{E_2^2}{R}}{\frac{E_1^2}{R}}$$

This may be restated as

$$\text{dB} = 10 \log \left[\frac{E_2}{E_1} \right]^2$$

Which in turn may be stated

$$\text{dB} = 20 \log \frac{E^2}{E_1}$$

Thus the statement

$$\text{dBmV} = 20 \log \frac{\text{E (voltage measured)}}{\text{E (voltage reference)}}$$

is perfectly valid, since we are still referencing to 0 dBmV. The term "20 log" is rational for measurements and calculations of voltage, and the term "10 log" is rational for measurements and calculations of power. A few example calculations may reinforce our understanding.

Example 1: A voltage measurement shows 3.16 millivolts (mV) across a subscriber service drop cable at the tap location. What is this signal level in dBmV?

Formula: $\text{dBmV} = 20 \log \frac{\text{E (measured)}}{\text{E (reference)}}$

$$= 20 \log \frac{.00316}{.001}$$

$= 20 \log 3.16$ (log of 3.16 is.4996)

$= 20 \times .5$

$= +10$ dBmV

Example 2: A voltage measurement shows 39.8 millivolts (mV) at the output of an amplifier. What is the level in dBmV?

Formula: $\text{dBmV} = 20 \log \frac{\text{E (measured)}}{\text{E (reference)}}$

$$= 20 \log \frac{.0398}{.001}$$

$= 20 \log 39.0$ (log of 39.8 is 1.5998)

$= 20 \times 1.6$

$$= +32 \text{ dBmV}$$

Power and Voltage Calculations

A brief review of the formulas we have applied may be helpful.

To calculate power ratios in dB:

When input is in power units:	When input is in voltage units:
$\text{dB} = 10 \log \frac{P_2}{P_1}$	$\text{dB} = 20 \log \frac{E_2}{E_1}$

To calculate signal level in dBmV:

When measurement is power:	When measurement is voltage:
$\text{dBmV} = 10 \log \frac{P \text{ (meas.)}}{P \text{ (refer.)}}$	$\text{dBmV} = 20 \log \frac{E \text{ (meas.)}}{E \text{ (refer.)}}$
$\text{dBmV} = 10 \log \frac{P \text{ (meas.)}}{.0133 \times 10^{-6}}$	$\text{dBmV} = 20 \log \frac{E \text{ (meas.)}}{.001}$

Example: In Figure 2-4 we show an amplifier inserted into a section of coaxial cable. The input signal power has been measured and was found to be 53.1 nano-watts (a nano-watt is one billionth of a watt, 10^{-9}). The output signal power has been measured and found to be 13.3 microwatts (a micro-watt is one millionth of a watt, 10^{-6}). What is the amplifier gain in dB?

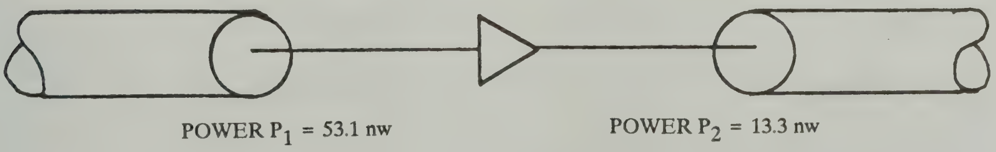


Figure 2-4 Power Ratios

Input Calculations

$$\text{dBmV} = 10 \log \frac{P_1}{.0133 \times 10^{-6}}$$

$$= 10 \log \frac{53.1 \times 10^{-9}}{13.3 \times 10^{-9}}$$

$$= 10 \log 3.99922$$

$$= 10 \times .6$$

$$= +6 \text{ dBmV}$$

Output Calculations

$$\text{dBmV} = 10 \log \frac{P_2}{.0133 \times 10^{-6}}$$

$$= 10 \log \frac{13.3 \times 10^{-6}}{.0133 \times 10^{-6}}$$

$$= 10 \log 1{,}000$$

$$= 10 \times 3$$

$$= +30 \text{ dBmV}$$

Amplifier gain is 30 - 6 = 24 dB.

Example: In Figure 2-5 we show the same amplifier as in the previous example but the signal level measurements were voltage measurements. The input signal voltage has been measured and found to be 2 millivolts or .002 volts. The output signal voltage has been measured and found to be 31.6 millivolts or .0316 volts. What is the amplifier gain in dB?

Input Calculations

$$\text{dBmV} = 20 \log \frac{E_1}{.001}$$

$$= 20 \log \frac{.002}{.001}$$

$$= 20 \log 2$$

$$= 20 \times .3$$

$$= +6 \text{ dBmV}$$

Output Calculations

$$\text{dBmV} = 20 \log \frac{E_2}{.001}$$

$$= 20 \log \frac{.0316}{.001}$$

$$= 20 \log 31.6$$

$$= 20 \times 1.5$$

$$= +30 \text{ dBmV}$$

Amplifier gain is 30 - 6 = 24 dB.

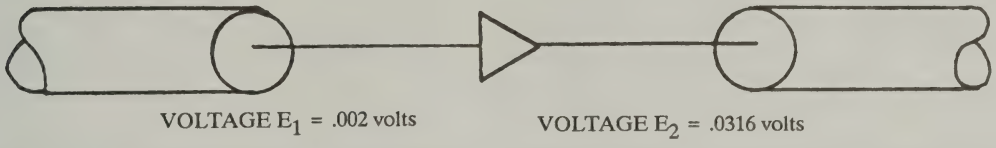


Figure 2-5 Voltage Ratios

Note that in these examples we used both power and voltage measurements and the calculated results were the same.

Summary

The calculations required in coaxial cable system design and operation are neither complex nor sophisticated if we fully understand the terms involved, and are familiar with how they interact with each other.

When we are addressing noise power in system calculations, for example, as when calculating carrier-to-noise ratios, the term "10 log" will apply.

When we are addressing voltage, for example, when we are calculating intermodulation products such as cross modulation, the term "20 log" will apply.

This fact will account for the phenomena that a one dB change in amplifier input level will have a one dB effect on carrier-to-noise ratio, while a one dB change in amplifier output level will have a two dB effect on amplifier intermodulation distortion.

Chapter 3

Introduction to Equipment

A logical point of departure for our study of CATV transmission systems is to identify all component parts of a system so that later references will not be completely unfamiliar or confusing.

Amplifiers

As the name implies, any amplifier is intended to accept low amplitude or weak signals at its input and reproduce these signals at a higher amplitude at its output. Thus amplifiers can and do compensate for transmission losses in coaxial cable systems, and at the transmission frequencies usually encountered in CATV systems, cable losses are such that re-amplification is required quite frequently. Thus, practical CATV systems of any significant size often involve serial connections of a number of units in what the industry refers to as "cascade." Serial connection is when the output of one unit is connected, in CATV systems through a relatively long section of coaxial cable, to the input of a subsequent unit.

All amplifiers are power-consuming devices, that is, they require operating power of some sort, and each amplifier will introduce some noise and distortion into signals passed through it. Later we will discuss the technical considerations of noise and distortion in greater depth.

Amplifiers are available in a variety of configurations designed for specific applications within a system. Figure 3-1 shows a diagram of an amplifier in its simplest form.

Amplifiers in CATV systems draw operating power directly from the coaxial cable itself. An alternating current (AC) voltage (usually 60 volts) is applied to the cable at periodic power insertion points, and all devices such as taps, couplers, splitters, etc., must be able to pass this ac voltage through to power subsequent amplifiers.

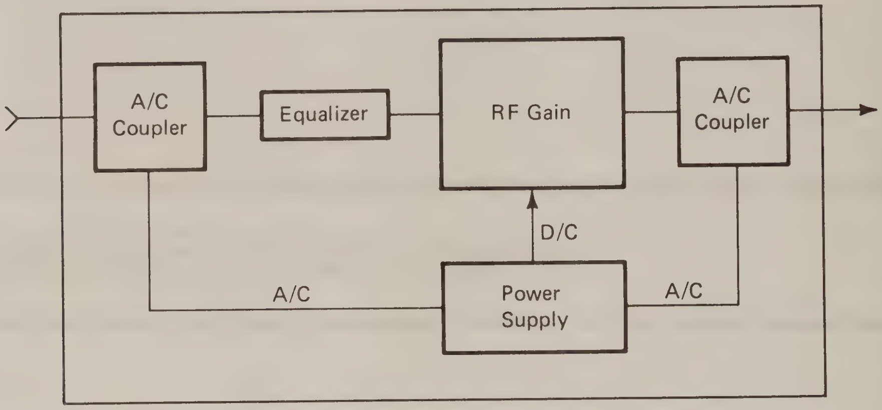

A/C
Coupler
Equalizer
RF Gain
A/C
Coupler
D/C
A/C
Power
Supply
A/C

Figure 3-1 Basic One-way Amplifier

Within the amplifier housings, two distinctly separate transmission paths are derived by use of low-pass filters such that the 60-Hz AC can be accessed independent of the RF transmission path. An amplifier power supply rectifies, regulates, and filters this ac and delivers operating direct current (DC) to the amplifier modules.

By adding RF filters, the transmission spectrum can be further divided within the amplifier housing, and an additional amplifier module can be inserted such that the amplifier offers gain in both directions through the housing. These filters are shown in Figure 3-2, and for clarity in this and subsequent drawings, the powering circuitry has been deleted. Thus, a single coaxial cable can be equipped to operate as a bi-directional or two-way transmission system.

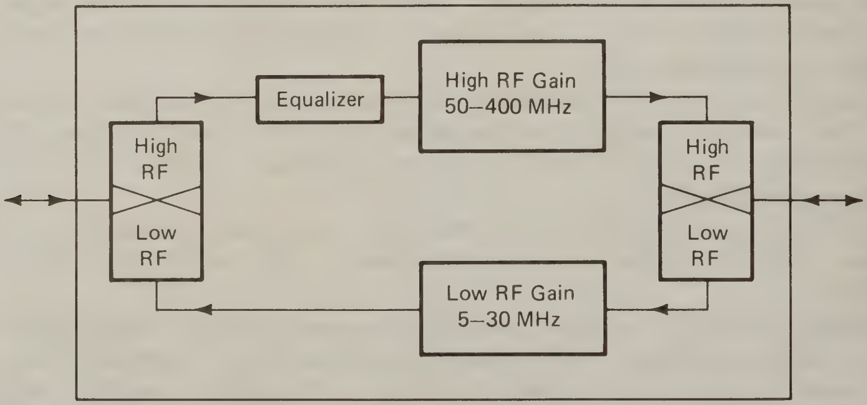

Equalizer
High RF Gain
50–400 MHz
High
RF
Low
RF
High
RF
Low
RF
Low RF Gain
5–30 MHz

Figure 3-2 Basic Two-way Amplifier

The design of the filter will determine the transmission bandwidth provided for each direction of transmission and several options are available. Figure 3-2 shows one of the most common allocations, a Sub-Split arrangement, but other configurations are possible as we discussed in the previous chapter.

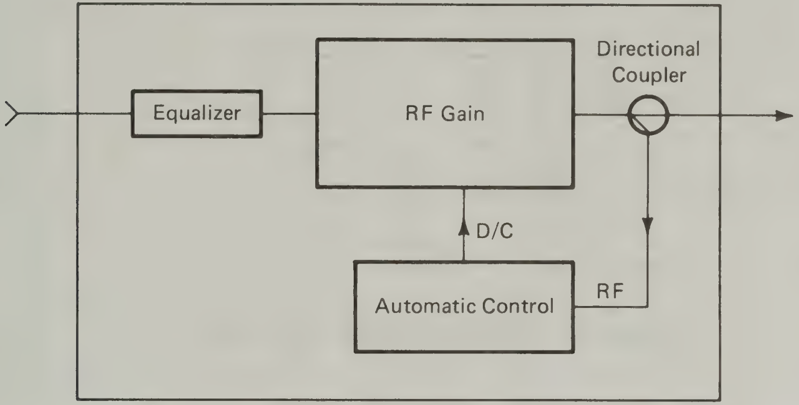


Figure 3-3 One-way Automatic Control Amplifier

Systems of any significant length require some degree of automatic self-regulation such as automatic gain control (AGC) and/or automatic slope control (ASC). Figure 3-3 shows, in block diagram, a one-way amplifier so equipped. Within the housing itself the primary gain module RF output is sampled through a directional coupler (see Figure 3-3), and this RF sample is applied to the automatic control module. After processing this RF, the control module delivers control voltages to regulate the gain module itself.

One amplifier configuration quite commonly encountered actually employs two separate gain modules within a single housing. The primary unit would amplify the "through" signals, and the secondary unit (called a bridger amplifier) would tap a low-level input off the through cable and produce an independent high-level output for feeding local distribution (feeder) cables. The housing itself may include some facility for distributing this high-level output to feed any of several cables. Figure 3-4 shows a main and bridger unit with signal-director (signal splitting) capability in a one-way transmission system.

Figure 3-5 shows this same unit with the return amplifier added as in a two-way transmission system. The flow of information for both directions of transmission are shown, and it will be instructive to follow all transmission through the unit in both directions.

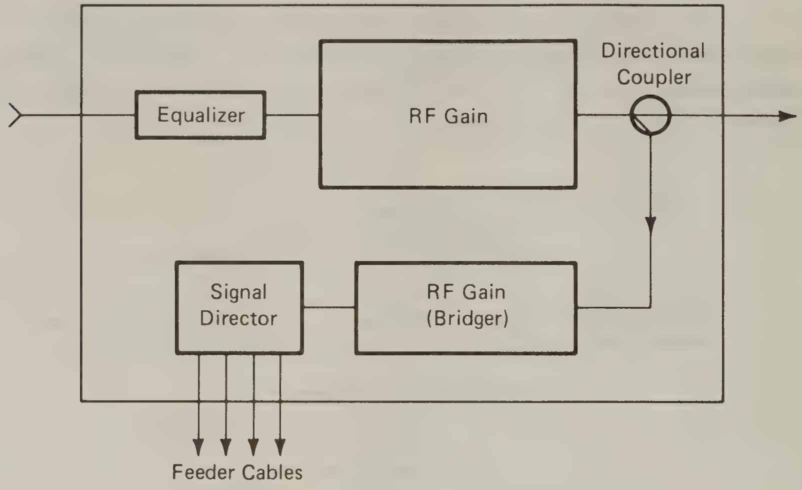


Figure 3-4 One-way Amplifier with Bridger

High-frequency energy launched into the distant end of a coaxial cable enters the housing on the left hand side of the drawing. This energy is presented to the common port of a high-low RF filter. This unit is designed so that the high requency signals see a high impedance at the low frequency side, and thus exit the unit out of the high frequency port. They pass through an equalizer, the purpose of which will be covered in a subsequent chapter, and are presented to the input of the high frequency RF gain module.

After being amplified, the signals are presented to a directional coupler unit. One output of this unit passes some high frequency RF energy on to another high-low RF filter which is identical to the one we encountered on first entering the housing. Again, the high frequency signals encounter a high impedance on the low-frequency side of this filter, and the high RF signals are launched into the coaxial cable that exits the housing, and propagate down the cable to subsequent devices or amplifiers.

The second port of the directional coupler we mentioned a moment ago directs some of the high frequency energy to the input of a bridger gain module, which functions just as we described for Figure 3-4. The output of the bridger gain module is again presented to a high-low RF filter at the high frequency port. These signals see a high impedance in the low frequency port of this filter, and thus are directed to the common port output of the device. Here they enter a signal director or signal splitting unit, and are subsequently launched into two or more distribution or feeder cables.

In this manner, downstream high frequency RF signals are amplified when required, and more than that. By using separate gain modules for "through" or trunk cable service and for distribution or feeder cable service, we have individual signal level control.

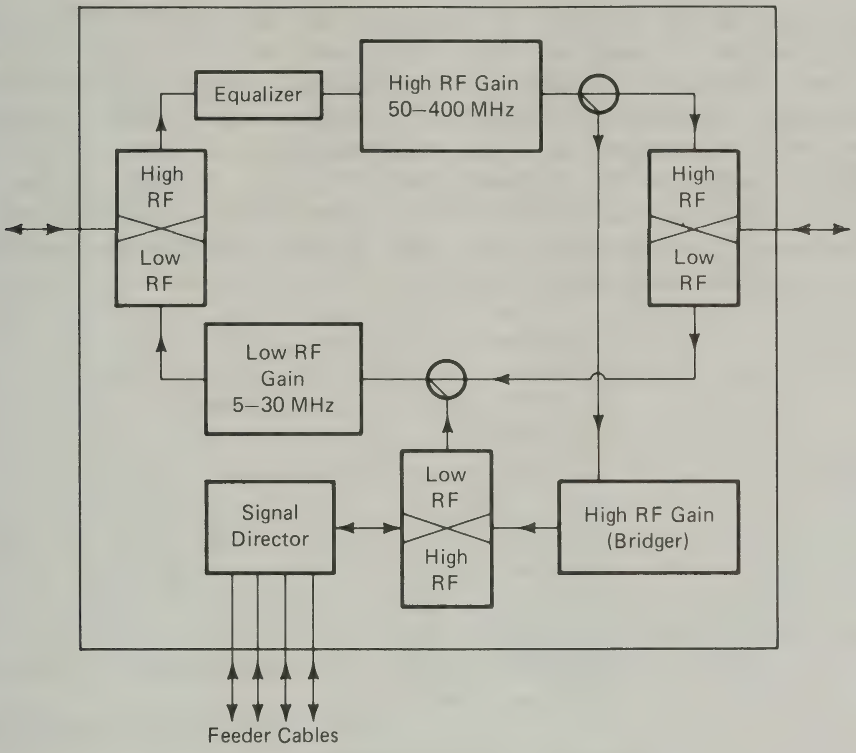

Equalizer
High RF Gain 50–400 MHz
High RF
Low RF
High RF
Low RF
Low RF Gain 5–30 MHz
Low RF
High RF
Signal Director
High RF Gain (Bridger)
Feeder Cables

Figure 3-5 Two-way Amplifier with Bridger

Both both trunk and feeder signal outputs have independent gain module gain controls. We can, if we so desire, set trunk and feeder signal output levels at different amplitudes. The utility of this flexibility will become apparent as we progress through the text.

Let us trace the signal flow for upstream transmissions. Low frequency RF energy would be presented to the housing on the cable that enters from the right hand side of the drawing. These signals would originate further down the system, of course. They are presented to the common port of the high-low RF filter, and see a high impedance at the high frequency port of this device, so they exit out of the low frequency port. They pass through a signal combining device and are presented to the input port of the low frequency gain module.

After amplification, the low frequency energy is presented to the low frequency port of the high-low RF filter at the left hand side of the drawing. These signals see a high impedance at the high frequency port of this device, so they exit on the filter common port and are launched into the coaxial cable that is connected to this port.

Low frequency signals collected by the system on distribution or feeder cables will enter the amplifier housing on these cables, and since the signal director or splitter has no directional or frequency discriminating qualities, these signals will transit through this unit and be presented to the common port of the high-low RF filter. They see a high impedance at the high frequency port of this filter so they exit the filter through the low frequency port. They are presented to the signal combining device, usually a directional coupler is employed, and are combined with the other low frequency, upstream signals that came in from the right hand cable, and which we have already traced through the amplifier.

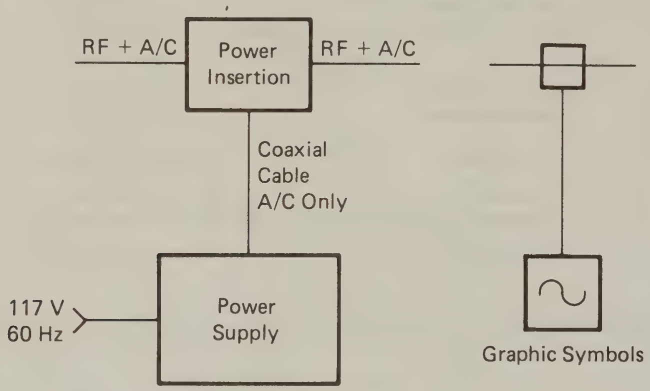


Figure 3-6 AC Power Supply

Keep in mind that a third transmission path exists through the housing, using the same coaxial cables, and that is the very low frequency path that is employed to power the amplifiers throughout the system. As we mentioned earlier this path has been omitted from the drawings for clarity, but it does exist as shown in Figure 3-1.

The variety of amplifier configurations available is quite large, in some cases including redundant or back-up modules for every active unit in the housing, but essentially they are all combinations of those we have described. The reader should be able to trace signal flow through even the most complex combination given a basic understanding of the internal elements of an amplifier, and their functions.

Ancillary features for operational status or failure alarm reporting plus re-motely addressed switching of return transmission from secondary cables are also available, and will be discussed elsewhere in the text. Amplifier housings are typically weather-tight, aluminum castings with hinged covers that may be mounted out-of-doors either on poles, or suspended directly from cable-supporting messenger wires, or may be adapted for pedestal mounting in underground systems.

AC Power Supplies

Within a system, power supplies are periodically mounted either on a pole in a weatherproof cabinet, or in a pedestal housing for underground installations. These power supplies require primary input from the local commercial power distribution system (usually 117 volt, 60 Hz AC) and produce a lower voltage AC (typically 60 volts) for application to the coaxial cable itself. The units include regulation to accommodate input voltage variations. The output is most generally a modified square wave rather than sinusoidal, which permits a more efficient transmission of power.

The coaxial cable may be physically extended to and through the power supply itself to apply the 60 volt AC, but more frequently a power insertion unit as shown in Figure 3-6 is used. This unit has a very nominal RF insertion transmission loss and the RF energy is restricted entirely from the AC port. Power may be applied as necessary to both or either of the RF ports by connections within the inserter itself.

The system power supplies should not be confused with individual amplifier power supplies. System supplies accept 117 Volt 60 Hz commercial power input, and produce 60 volt 60 Hz output which is used to extend operating power to a number of amplifiers within a section of the system. Individual amplifier power supplies are modules within an amplifier housing that accept the low voltage 60 Hz energy from the coaxial cable, rectify it to DC and regulate it, and thus provide direct operating power for the active modules located within that individual equipment housing.

Passive Devices for Coaxial Systems

A variety of devices are required in practical coaxial transmission systems to accommodate cable side leads or spur lines and to supply signal feeds to subscriber service drop cables, also. These devices are considered passive since they do not provide amplification or gain and do not consume or require operating power to perform their functions. However, they may have to pass AC power through them in order to supply subsequent active devices, such as amplifiers. These devices may be characterized as belonging to three major basic categories:

1. Splitters

2. Directional couplers

3. Subscriber taps

The coaxial cable itself, and most passive devices required in constructing systems, are inherently bi-directional in nature. Thus, two-way coaxial systems are relatively easy to develop once the problem of bi-directional amplification has been resolved.

Splitters

A splitter is a device that equally divides the input RF energy between two outputs. It is convenient to refer to the splitter loss in decibels (dB). If half the power is directed to each of two output ports, the RF energy available at each output port would theoretically be 3 dB lower than the single input port signal level was. But the splitter itself has some inherent loss, so a two-way splitter would typically be specified as introducing 3.5 dB or more of transmission loss to each of two output ports. Combinations of splitters are possible to produce three- or four-way outputs (see Figure 3-7), and in this case the transmission loss is simply a function of how many times the input energy has been divided in half. For example, note that the three-way splitter shown has one output port with a 3.5 dB, loss and two output ports with a 7 dB loss.

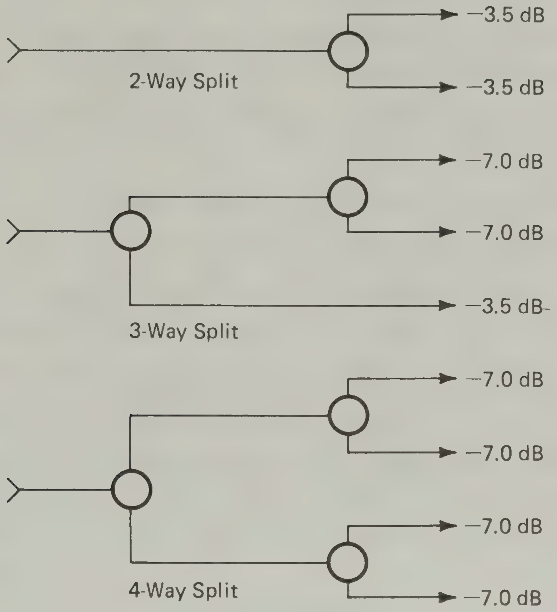
Since power to operate amplifiers is also passed through the system as well as the RF signals themselves, splitters are equipped with circuitry to pass the 60 Hz power independently of the RF energy. Power may be passed through to all output ports, or back through to the input port from any output port, without affecting the RF transmission characteristics of the unit. It is also possible to isolate any specific leg or port for AC power purposes without affecting RF transmission. Figure 3-8 shows the power passing function of a splitter.

Splitters may also be used to combine two RF sources into one output and are often employed for this purpose in CATV head ends. A splitter does not have any directivity from the input to any output port, but some isolation or higher loss is introduced between output ports themselves. And as in all coaxial system devices, splitters are specified as to return loss by the manufacturer, and we will examine return loss later in the text.

Splitters are available for outdoor, strand-mount installation and also in indoor configurations for use in subscribers' homes to serve second television sets, or at head ends to combine signals. Indoor versions normally do not include power passing circuitry.

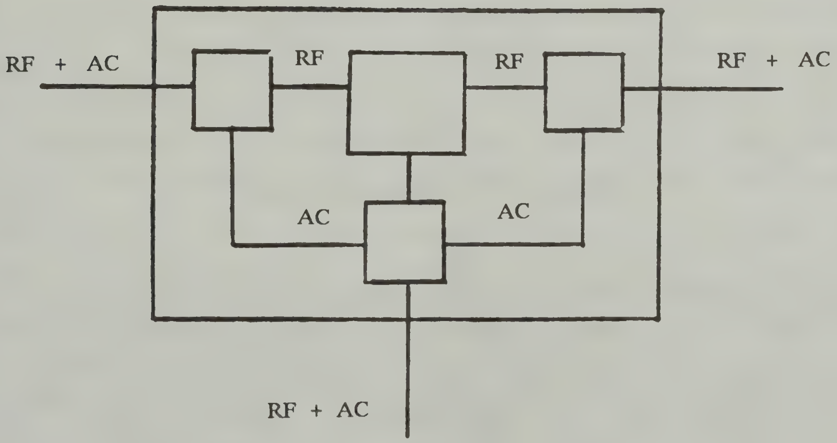
The parameters usually specified for splitters would include the following:

1. Number of output ports
2. Bandpass in MHz
3. Insertion loss in dB
4. Return loss in dB
5. Isolation between output ports in dB
6. AC current-passing capacity in amperes



−3.5 dB
2-Way Split
−3.5 dB
−7.0 dB
−7.0 dB
−3.5 dB
3-Way Split
−7.0 dB
−7.0 dB
−7.0 dB
4-Way Split
−7.0 dB

Figure 3-7 Splitters



RF + AC
RF
RF
RF + AC
AC
AC
RF + AC

Figure 3-8 Power Bypass

Directional Couplers

A directional coupler may be employed when only a part of the main cable RF energy need be diverted to a side lead or spur cable feed. By choosing the value of the coupler, the signal level presented to the side lead can be preselected. As the name implies, the directional coupler has directivity. In Figure 3-9 we show a directional coupler.

RF energy applied to the input port of the device will pass through the device and appear at the primary output port. The tap port will also receive some of the input RF energy, and the amount of energy tapped off will depend upon the decibel value of the coupler. Quite obviously, if more energy is tapped off, less energy will be available at the primary output port. The coupler will exhibit high loss at the output port to any signals presented to the tap port; this is called isolation. RF energy reflected into the tap port due to impedance mismatch or other system irregularity would appear at the input port attenuated by the coupler value, but the reflected RF energy appearing at the output port of the device would be attenuated by much more than just the coupler value, as shown by the values in Table 3-A, which are one manufacturers values for units presenting transmission bandwidth to 300 MHz.

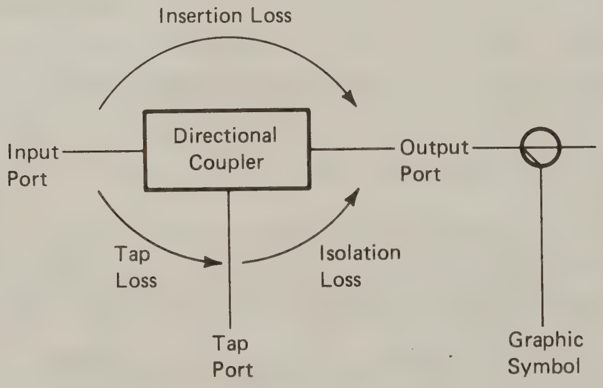


Figure 3-9 Directional Couplers

Directional couplers are used within amplifier housings also, to tap off lower levels of energy as input signals to bridging amplifiers, for amplifier test points, and in AGC and ASC amplifiers. Because of the isolation they can provide, directional couplers are sometimes used in head ends to combine the outputs of signal-processing equipment. Amplifiers may have plug-in directional couplers or splitters in their output circuitry to provide for separate cable feeds. Just as with splitters, power bypassing circuitry is usually built into outdoor type couplers, as we showed earlier in Figure 3-8 for splitters, and indoor versions usually do not pass power.

Table 3-A Directional Coupler Parameters

Coupler Value (dB)	Insertion Loss (dB)	Loss to Tap (dB)	Isolation (dB)
7	1.7	7.3	22
10	1.1	10.6	25
13	0.8	12.7	28
16	0.6	16.2	31
20	0.4	20.6	35

The specifications for a directional coupler would include:

1. Tap value in dB
2. Bandpass in MHz
3. Insertion loss in dB
4. Return loss in dB
5. Isolation (output to output) in dB
6. AC current-passing capacity in amperes

Subscriber Taps

Taps are utilized to tap off RF energy from a coaxial cable to feed subscriber service drop cables. Taps are available to feed two, four, or eight service drops from any one unit. Since the signal levels will be different at different points along the cable system, and since we have to tap the cable at different points also, a variety of tap values is made available. In this manner we can present relatively the same signal input level to all subscriber service drops regardless of where they may be positioned along the cable.

In Table 3-B, the numeral 2 denotes a two-port tap, and the numeral 4 denotes a four-port tap. Taps designated with a T suffix such as the 2T and the 4T, are terminating taps, and there is no output cable port in such units. They are employed exclusively at ends of cable runs where no cable extension is required.

Modern directional coupler type taps might be considered as a combination of a directional coupler and a splitter or several splitters. Figure 3-10 shows a directional coupler feeding a four-output tap, which is developed by cascading one splitter with two more splitters behind it.

The insertion loss, tap-to-output isolation, and input-to-tap losses are similar to the directional couplers discussed earlier.

Table 3-B Subscriber Tap Parameters

# of Ports	Loss to Tap (dB)	Insertion Loss (dB)	Isolation (dB)
2T	4	---	---
2	8	2.8	23
2	11	1.5	26
2	14	1.0	29
2	17	0.7	32
2	20	0.6	35
2	23	0.4	38
2	26	0.4	41
2	29	0.4	44
2	32	0.4	47
4T	7	---	---
4	11	2.8	26
4	14	1.7	29
4	17	1.0	32
4	20	0.7	35
4	23	0.6	38
4	26	0.4	41
4	29	0.4	44
4	32	0.4	47

In addition, taps are designed to provide relatively high isolation loss between individual tap outputs, as shown in Figure 3-10, to minimize undesired interference between subscriber stations that are fed from the same tap.

The selection of a specific tap value is made during system layout and must consider the signal level desired to feed the service drop, and the signal level availablein the transmission cable at the point where the tap is to be located. For example, if the system designer has specified a +10 dBmV signal level at all service drop inputs, and the signal level at the point where the tap is to be located was +33 dBmV, a 23 dB value tap could be used. This would produce +10 dBmV at each of the tap ports, since the input signal level was +33 dBmV, and would impose an insertion loss into the tapped cable of 0.4 dB if it was a two-output tap, and 0.6 dB if it was a four-output tap.

Taps for outdoor, strand-mounting service pass AC power through them to provide power for subsequent system amplifiers, just as splitters and couplers do, and we show this power passing capability in Figure 3-11.

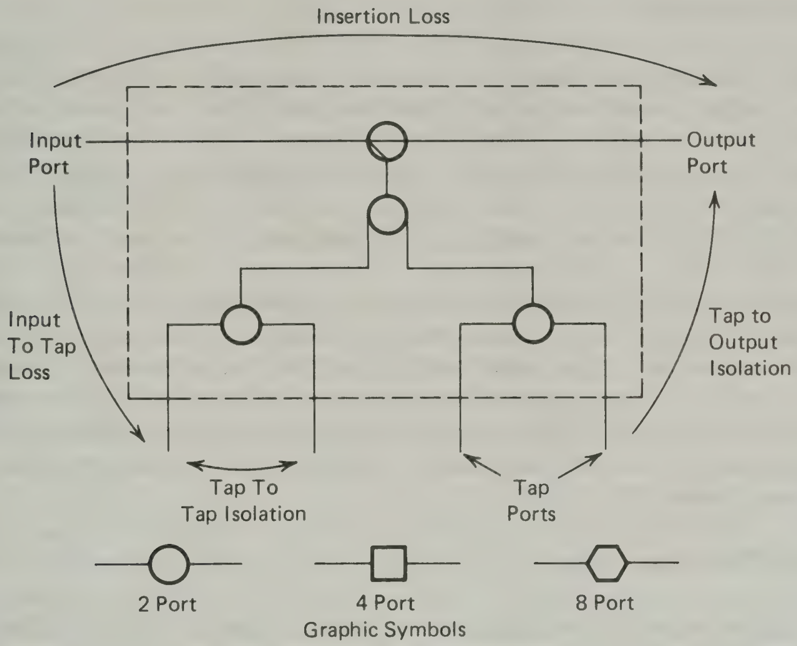

Insertion Loss
Input Port
Output Port
Input To Tap Loss
Tap to Output Isolation
Tap To Tap Isolation
Tap Ports
2 Port
4 Port
8 Port
Graphic Symbols

Figure 3-10 Four-port Subscriber Tap

If a non-terminating tap is installed at the end of a cable run, the output port of that tap must be terminated to avoid RF reflections from an impedance mismatch. Outdoor taps do not usually pass AC power to the service drops, and in apartment house or motel installations, indoor versions of directional coupler taps are used that do not pass power at all.

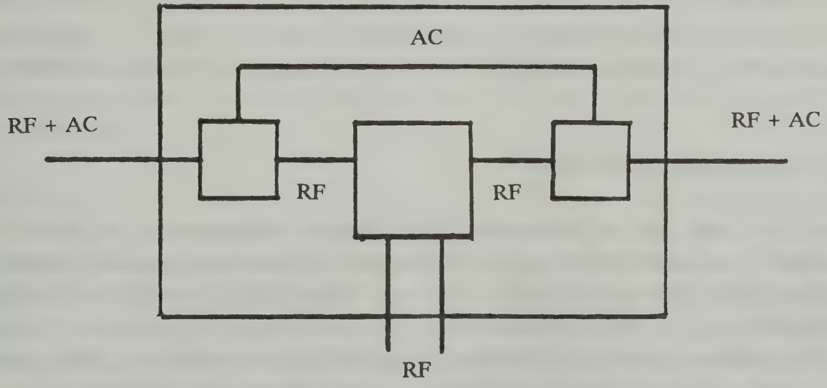

AC
RF + AC
RF + AC
RF
RF
RF

Figure 3-11 Power Bypass

Active Subscriber Taps

Although the taps we have just discussed are entirely passive, that is, they require no operating power to perform their functions, there are some subscriber taps that are active units and do consume operating power. These units are employed in systems where some signal treatment is performed right in the tap itself, rather than inside the subscribers' premises. One philosphy of system design transfers a significant amount of subscriber terminal sophistication from the subscribers' premises to the system tap instead.

In such systems the tap devices are quite sophisticated and do require some operating power source. Typical functions performed by active taps of this type are frequency conversions and signal descrambling, such as the subscriber converter might do in other systems, and many units of this type are addressable from the system head end, and can be activated or disabled without an actual visit by a technician. Some of these units can perform all the functions of the subscriber terminal units we discussed in Chapter 1 (see Figure 1-12).

Other Passive Devices

There are a variety of ancillary passive devices used in coaxial cable systems. Terminators, one example, are units used to terminate cable ends or unused ports of devices so that no impedance mismatch is created and RF reflections and echoes are minimized. Terminators would be placed on tap output connections where no subscriber service drop is initially connected. An assortment of plug-in devices located within the amplifier housing itself are used in conjunction with amplifiers, for example, pads or attenuators, equalizers, bi-directional filters, and thermal equalizers.

An equalizer is used to correct or introduce frequency response distortion, for example, to perhaps "tilt" the response of the amplifier, or to compensate for response tilt introduced by the interconnecting coaxial cable. Bi-directional filters separate sections of the system spectrum such that some spectrum can be used for transmission in one direction and other portions of the spectrum can be used for transmission in the reverse direction. We shall discuss these devices in greater detail elsewhere in the text.

Specifying Transmission Bandwidth

In Tables 3-A and 3-B we presented transmission characteristics of some typical directional couplers and subscriber taps. Note that the devices specified were identified as presenting 300 MHz of bandwidth for use. When the bandwidth of a system is established, for example, as 300 or 400 MHz, then all devices employed in that system must present that same transmission bandwidth capability, or greater. We cannot use couplers or taps that are specified only to 300 MHz in a broader bandwidth system.

When the bandwidth of a device is specified, and a transmission loss is also called out, it means that the device will not present more transmission loss than that called out to any signal whose frequency is within the specified bandwidth of the device. For example, a coupler specified to present 7 dB of loss to the tap port and identified as a 300 MHz device, will not present more than 7 dB of loss to any signal 300 MHz or lower in frequency. It may present less loss than 7 dB in some portions of its transmission bandwidth, however.

In designing devices and amplifiers, it is difficult to achieve precisely the same transmission characteristics across the entire bandwidth of the device. As the bandwidth of systems is increased, from 220 MHz to 450 MHz, for example, then the bandwidth of all devices and amplifiers must be increased also. The variations in transmission characteristics for a broader band device will be more pronounced, and more difficult to minimize, than in a narrower band device.

When we design systems with relatively limited transmission bandwidth, say up to 300 MHz for example, then the variations across the band which we cannot entirely avoid in all devices may not be pronounced or significant. Then we can specify such devices adequately by calling out only one figure for each characteristic. For example, a 10 dB 300 MHz coupler as specified in Table 3-A, would present 1.1 dB insertion loss to signals passing through the unit and 10.6 dB of loss to signals tapped off the main cable. When utilizing this unit in a system design effort we will consider these single figures only, 1.1 dB and 10.6 dB, even though the unit might actually have 1.0 dB of insertion loss at say 220 MHz, and 10.4 dB of tap loss at 174 MHz. We would do all the system design calculations based upon only one set of figures, worst case or highest loss for example, even including the coaxial cable loss itself.

When the system bandwidth is greater, say 450 MHz or so, then the variations in device characteristics become more pronounced and cannot be completely ignored. We will find as we progress through the text, that devices are now specified with two figures for each characteristic, the lowest transmission frequency characteristic, and the highest transmission frequency characteristic as well. The coupler we discussed a moment ago, for example, might now be specified to have characteristics like 1.1 dB insertion loss at 450 MHz and 0.8 dB insertion loss at 54 MHz, with tap losses of 10.6 dB at 450 MHz and 9.5 dB at 54 MHz. Throughout the entire design effort we would calculate transmission losses at both the high frequency and low frequency ends of the system bandwidth.

Summary

There are too many configurations of equipment to consider them all here, but essentially they are all combinations of the units described above. If the basic function of each type of unit is clearly understood, it is possible to analyze any equipment combination by tracing the signal flow through it as we have done here.

Chapter 4

Noise

As transmissions pass through a coaxial system, the cable loss itself must be offset by inserting amplifier gain. Each such amplifier introduces both noise and distortion. Obviously the longer the system, the greater the number of the amplifiers required in tandem or cascade, and the higher the noise and distortion levels become. The objective is to produce acceptable quality transmission performance at the end of an economically practical system. The worst-case or poorest performance will be at the point in the system where the transported signals have been passed through the greatest number of amplifiers.

In this discussion we cannot avoid some introduction of formulas and mathematical calculations. These have been held to a minimum insofar as this is possible. For those readers who may wish to follow the development but not focus on the mathematical processes, key items in each calculation are underlined. The section of the Appendix entitled "CATV Calculations" presents all formulas used along with an explanation of each. The reader is encouraged to review the definitions of decibel (dB) and decibel-millivolt (dBmV) as presented in Chapter 2 before proceeding further.

Noise Impairment in TV Pictures

Although there are differences of opinion among many CATV engineers on how much noise can be tolerated in television pictures as delivered to subscribers, tests have been conducted by a number of parties and some standards for comparison are generally accepted. The visual appearance of noise is commonly referred to as "snow" in pictures, but noise does become perceptible to a viewer, and perhaps objectionable to some, at levels lower than that producing heavy "snow."

Just as audible noise in audio systems or telephone circuits is a matter of listener perception, so is the presence of noise in television pictures.

By that we mean, some levels of noise that might not be perceived by some viewers may be objectionable to a more sophisticated or trained observer. In the final analysis, the only method of establishing standard references is subjective viewing, where a large number of viewers are exposed to the same level of noise in a picture, and the results are collated in some manner. When standards for noise in telephone circuits were established, a comprehensive series of similar subjective tests were required.

One series of tests frequently referenced were conducted by the Television Allocations Study Organization (TASO) and the results were published in a report to the Federal Communications Commission (FCC) in 1959. Correcting these results to a 4 MHz bandwidth, we can construct Table 4-A.

Table 4-A TASO Ratings

TASO Picture Rating	S/N Ratio
1. Excellent (no perceptible snow)	45 dB
2. Fine (snow just perceptible)	35 dB
3. Passable (snow definitely perceptible but not objectionable)	29 dB
4. Marginal (snow somewhat objectionable)	25 dB

It is important to recognize that once the level of noise is below a level of visual perception, then improvements in the S/N ratio of a signal do not present any improveement in how the viewer sees the picture. If noise cannot be seen, then less noise is not perceptible as an improvement. But noise does accumulate in systems, and providing some margin for subsequent higher noise levels, such as might inadvertently develop through equipment problems or aging over a period of time, is sound and prudent engineering practice.

A widely accepted standard for an acceptable noise accumulation in a coaxial cable transmission system is 43 dB C/N ratio, which relates to a S/N ratio in a 4 MHz bandwidth of approximately 39 dB. The system designer is free to impose a more severe standard for C/N, but it must be recognized that some cost penalty will accompany such an action. It is beyond the scope of this text to pursue the matter of standards.

Instead, we will focus on understanding noise and its accumulation in systems, since any particular design effort can produce any level of transmission performance quality that may be required.

Noise Figure

Any amplifier, indeed a resistor alone, will generate some noise internally due to random electron movement within the conducting material itself. This may be called the thermal noise threshold, and if input signals were introduced at this same level of amplitude, they would be indistinguishable from the noise generated. In such a case the signal-to-noise (S/N) ratio would be zero, since there would be no difference in amplitude between the noise and the signal introduced.

The factors that are involved in calculating the noise generated in a device include the bandwidth of the device, the temperature of the device, and the impedance. Thermal noise in a theoretical, perfect amplifier can be shown to be -59 dBmV in a 4 MHz channel, which may be considered a TV channel in a 75 ohm system. Then no amplifier will introduce less noise than this.

An individual amplifier is specified by the manufacturer to have a noise figure (NF), usually stated in decibels. This identifies how close to the theoretical thermal threshold that particular amplifier performs or, stated another way, how much noise above the irreducible thermal noise threshold level (-59 dBmV) will be generated within the unit. This relationship is shown in Figure 4-1. We see that given a NF of 9 dB, the noise present in a 4 MHz channel would be 9 dB above the -59 dBmV thermal threshold, which would be -50 dBmV. Obviously, a lower value NF would indicate a better quality amplifier, since it produces noise which is lower in amplitude and thus less disruptive. A better (smaller) noise figure would improve the amplifier noise threshold, as it is shown in Figure 4-1. Ifthe noise figure were 7 dB, for example, then the amplifier would generate only 7 dB more noise above the theoretical threshold point of -59 dBmV, and thus the amplifier noise threshold would be -52 dBmV.

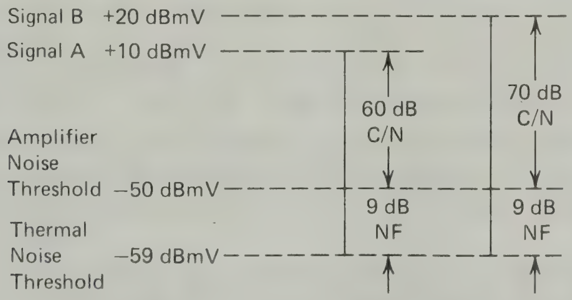

Signal B +20 dBmV
Signal A +10 dBmV
60 dB C/N
70 dB C/N
Amplifier Noise Threshold −50 dBmV
9 dB NF
9 dB NF
Thermal Noise Threshold −59 dBmV

Figure 4-1 Noise Figure

Once the selection of an individual amplifier has been made thus establishing the noise figure number, since the theoretical or thermal noise threshold will not change, the only factor that is under the system designers control as to how much noise an amplifier will introduce into that system is the signal level which is presented to the amplifier input. The designer may manipulate, by selection, the input signal level, and thus control the noise contribution.

This may be seen clearly by examining Figure 4-1 again. If the designer elects to present an input signal at a +10 dBmV level (Signal A in Figure 4-1), then the difference in amplitude (the ratio) between the input signal and the noise power level would be 60 dB, as shown in the figure. If the designer elects to present an input signal at a +20 dBmV level (Signal B in Figure 4-1), then the difference in amplitude (the ratio) between the input signal and the noise power level would be 70 dB, as shown in the figure.

There may be conditions under which an amplifier is operated that make it less important that the unit have a good noise figure. Consider if an amplifier were so located within a system that it was always presented with a high level of signal input. In such a case the C/N ratio may be so good that the system could tolerate a lower ratio without compromising end-of-system performance. The designer might elect, under these conditions, to purchase an amplifier with a poorer noise figure since a poorer noise figure may be easier to achieve in amplifier manufacturing, and thus may be less expensive.

Conversely, in a section of a system where the designer is obliged to work with very low input signal levels, such as the signal level from a distant TV broadcast station perhaps, the provision of a unit with an excellent noise figure may not be avoidable, and extra cost for such a unit would be justifiable.

S/N and C/N Ratios

In our discussions we will be largely concerned with RF carriers that have been modulated with intelligence (video and audio, for example), and with the noise which may be present in the transmission spectrum occupied by that RF carrier, thus the terminology carrier-to-noise ratio (C/N) is appropriate. But if we demodulated the intelligence off the RF carrier (as a television receiver does, for example), we would recover the original information, be it video, audio, or whatever, and in that original form (video, audio, etc.) we will also find noise present. We can measure both the signal and the noise and establish the ratio between them. This is commonly referred to as signal-to-noise (S/N) ratio and, by definition, S/N is the ratio between the baseband or unmodulated information present and the noise present within the same spectrum.

Carrier-to-noise (C/N) is the ratio between the carrier signal present and the noise present within the same spectrum. Just as with S/N, we can measure both the noise present in a 4 MHz slot, and the carrier amplitude of a signal present in that same slot.

There is a relationship between C/N and S/N ratios. If the RF transmission system were particularly noisy (produced a poor C/N ratio), the demodulating device would have greater difficulty differentiating between the carrier and the noise. The result would be a poorer S/N ratio in the original information. For any given RF C/N ratio, the S/N ratio is generally accepted to be 4 dB lower. Thus a CATV system that produces a C/N ratio of say 46 dB, would be expected to produce a S/N ratio, in any demodulated signal that it was carrying, of 42 dB.

However, in addressing the transmission system itself (the coaxial cable system), we need clearly defined performance interface points. We are going to have to specify performance through the cable plant alone, and we must be able to measure and verify that performance through the cable plant alone. Since all signals pre-sented to, passed through, and recovered from the cable plant are RF carriers in CATV operations we usually confine ourselves to C/N ratios in technical discussions.

Carrier-to-Noise Ratio

In system design and analysis it is much more convenient to use the ratio between the noise level and the transported RF carriers than the actual noise power level itself. This ratio is referred to as carrier-to-noise (C/N) ratio and is much more conveniently measured, as well as more adaptable for engineering computations. As stated earlier, the C/N ratio is the difference in amplitude between the desired RF carrier and the noise present in that portion of the spectrum occupied by the desired signal. It is expressed in decibels to denote the ratio or relationship between the two.

The nature of internally generated thermal noise is not frequency sensitive, that is, the noise present is the same amplitude across the entire spectrum under discussion. Viewed on an oscilloscope, the noise would appear as a broad signal which is relatively the same amplitude across the entire band measured. If the spectrum of interest is limited, for example, in a voice channel of say 3 KHz bandwidth, only the noise present in the 3 KHz that is occupied by the audio information itself is of concern.

In a broadband system such as a coaxial system we must concern ourselves with the noise present in a 4 MHz channel, which is a single TV signal, but noise that is present elsewhere within the system spectrum will have no detrimental effect on the TV signal which is in the 4 MHz we are addressing. Thus, noise contribution in broadband systems is independent of how many TV channels the system is carrying, and since the noise power is the same amplitude across the entire system spectrum. In effect, noise considerations are identical for all channels in a system, regardless of how many or how few channels the system may be carrying.

Calculating C/N Ratio

The formula for computing the C/N ratio for a single amplifier is:

$$C/N = Sig_{in} + 59 - NF$$

where C/N = C/N ratio for a single amplifier in dB

Sig_{in} = input signal level in dBmV

59 = thermal noise in a 4 MHz band

NF = Amplifier noise figure in dB

For example, an amplifier with a 9 dB NF and presented with a +5 dBmV input signal would produce a C/N ratio of 55 dB from

$$C/N = Sig_{in} + 59 - NF$$

$$= +5 + 59 - 9$$

$$= 55 \text{ dB}$$

It is possible, and may be convenient, to construct a nomograph that reflects the relationship of the three factors and can be used with a straight edge or ruler. On the nomograph shown in Figure 4-2, a straightedge used to connect a +5 dBmV input level on the left hand vertical scale with a 9 dB noise figure on the right hand scale will indicate a 55 dB C/N ratio on the center scale. This agrees with the above calculation.

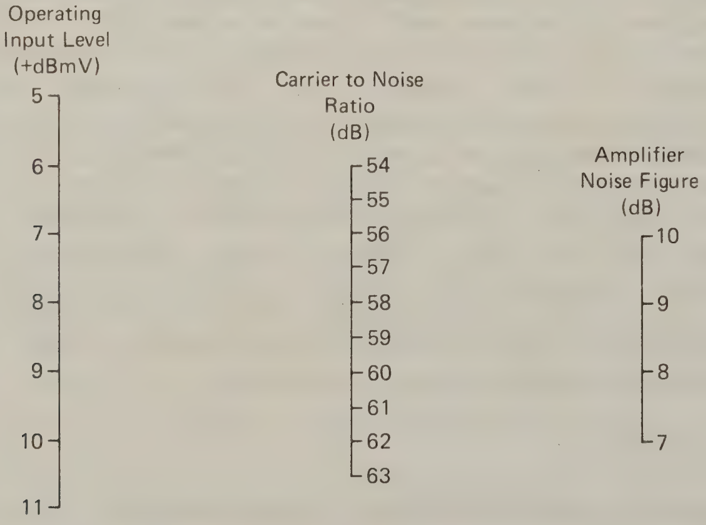


Figure 4-2 C/N Ratio Nomograph

One may determine C/N ratio by computation or by using a suitable chart such as the nomograph sample or, of course, by actual measurement on equipment. A few examples may help clarify carrier-to-noise.

Assume we wish to establish a C/N ratio of 58 dB. If we have an amplifier available with an NF of 8 dB, the nomograph quickly shows us that we must provide an input signal level of +7 dBmV to maintain a C/N ratio of 58 dB. In this same case, however, if we had an amplifier available with an NF of 7 dB, we could also use that one. We would now require an input signal level of only +6 dBmV while still providing our desired 58 dB C/N ratio. This is easily verified by using the nomograph in the figure.

Combining C/N Ratios

In constructing systems, we will be obliged to connect several amplifiers together in cascade and, in fact, several separate basic system elements as well.

For example, a system will include a signal source or head end, which will collect, process and combine a multiplicity of television signals. The processing involves the use of active or power consuming devices, and each such unit can and will introduce noise. Each amplifier in a string of amplifiers will also introduce some noise.

The net effect is that transmissions through the entire system will have incurred some noise addition from all these noise sources combined, and this can be calculated as the carrier-to-noise ratio of the total system. Then we cannot avoid having to combine individual C/N ratios for individual parts of a system to produce a composite or overall C/N ratio. Since we are discussing noise power, the combining or addition of noise power levels would be a power addition.

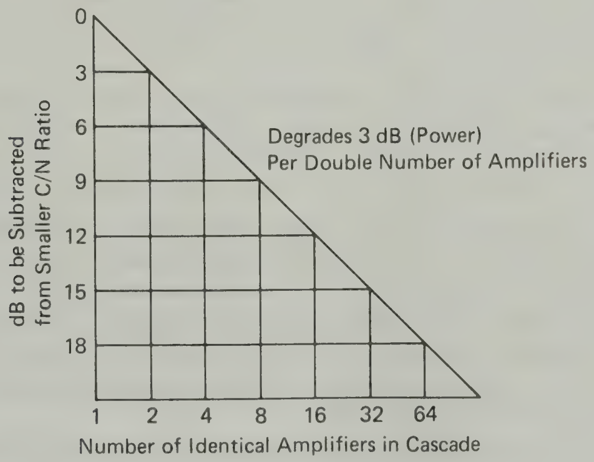


Figure 4-3 C/N and Amplifier Cascade

We can easily determine the noise power generated within a single amplifier. The addition of a second amplifier in tandem or cascade with the first would require the addition of two equal noise powers, if both amplifiers were identical, and both were receiving the same input signal level. Thus, if we double the number of ident-ical amplifiers, we are adding together two equal noise powers, and the resultant noise power would be 3 dB higher than either of the individual units produced.

But we have elected to use C/N ratio since it is more convenient. Increasing the noise power by 3 dB (twice as much noise power) would reduce the C/N ratio by 3 dB, since the noise increased by 3 dB but the input signal level remained the same. The chart in Figure 4-3 shows the relationship of C/N ratio to amplifier cascade when combining equal noise powers. Note that the chart specifically relates to doubling the number of identical amplifiers only, with all amplifiers operating at the same input signal level. The value of dB shown to be extracted would be subtracted from the C/N ratio of a single amplifier.

For example, suppose we had a cascade of sixteen identical units operating at the same input level, and the C/N ratio of each individual amplifier was 58 dB. We enter the chart in Figure 4-3 along the bottom scale at the number 16 and read up until we intersect the reference data line on the chart. We then read over to the left hand scale and find the value in dB to be subtracted is 12 dB. Subtracting 12 from 58 we establish the combined C/N ratio of 16 units to be 46 dB.

If we were not adding equal noise powers the chart in Figure 4-4 can be conveniently employed. This might be the case, for example, if we added five identical amplifiers operating at the same input levels to an existing cascade of, say, twelve amplifiers. In this case we would not be adding equal noise powers. This is also true if the amplifiers added had a different NF or were operating at a different input signal level. The chart will be particularly useful when we are required to combine the C/N ratio of a cascade of amplifiers with the C/N ratio that represents the quality or condition of head end signal output, since it is improbable that these ratios will be the same.

A few simple exercises with the application of the charts in Figures 4-3 and 4-4 may reinforce our understanding of C/N ratios. Assume we have an existing cascade of sixteen amplifiers that produces a combined C/N ratio of 46 dB. We want to add nine additional amplifiers of a different type, and these units present a combined C/N ratio of 49 dB. How can we establish the C/N ratio of the total cascade of 25 amplifiers?

Given the two ratios, 46 and 49, the difference between them is 3 dB. We enter the chart in Figure 4-4 at this value (3) on the bottom reference line. We read up until we strike the reference data curve, then we read left to the left hand reference scale. This indicates that we must subtract 1.8 dB from the poorer of the two C/N ratios. Since a 46 dB ratio is poorer than a 49 dB ratio, the resultant C/N ratio for the combined system will be 46 - 1.8 = 44.2 dB.

Suppose, using the same amplifiers as above, we were adding sixteen additional identical amplifiers to the original cascade of sixteen, and all of these were receiving the same input signal level also.

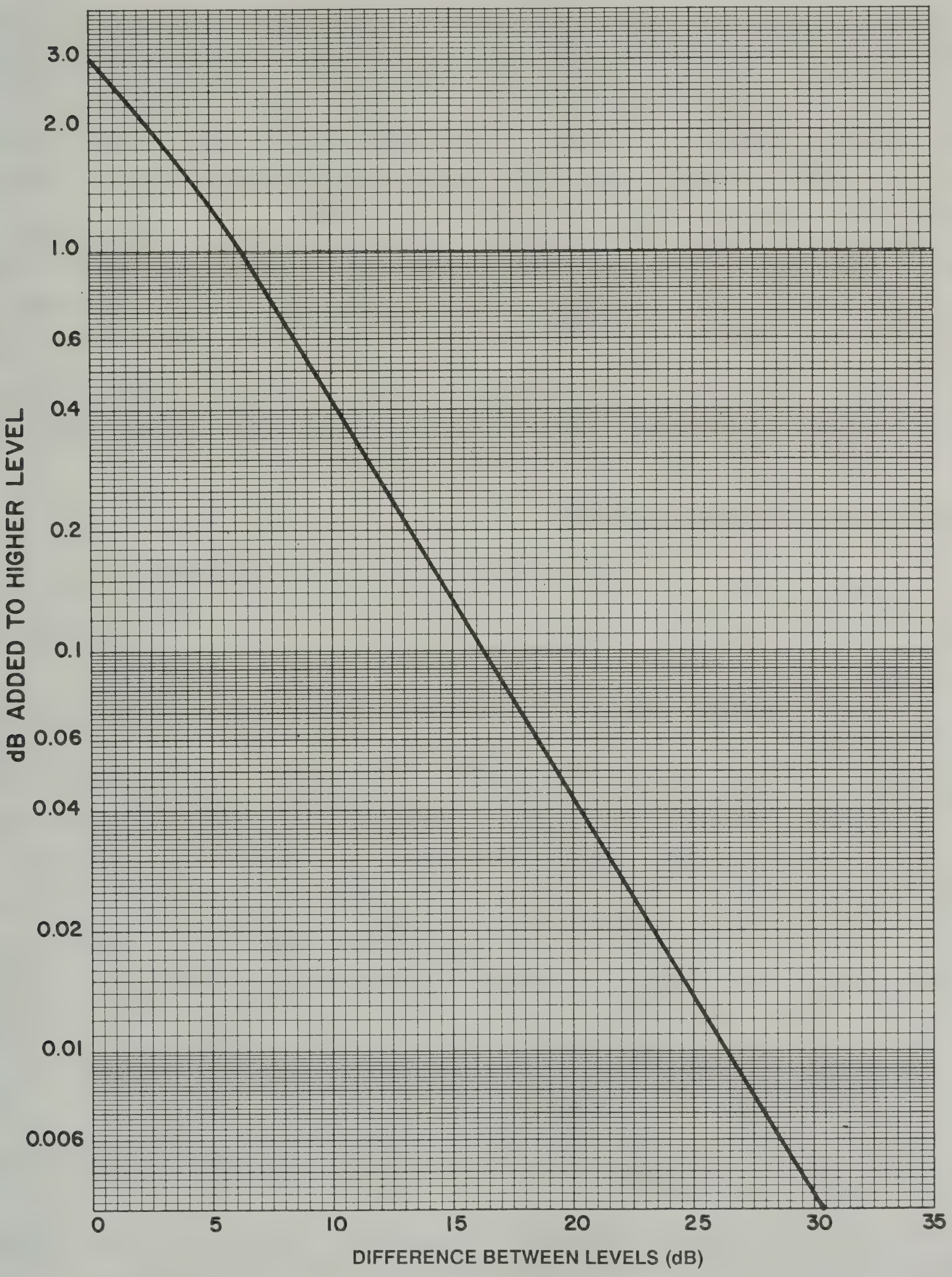


Figure 4-4 Combining Power (Noise) Ratios

Then the C/N ratio of the new cascade of 16 units would be the same as the ratio for the original 16 units. Now we are combining equal noise powers, or equal C/N ratios. In Figure 4-3, note that C/N will degrade by 3 dB every time we double the number of amplifiers, providing they are identical units. Adding 16 units to 16 units would be doubling the number of units, thus the C/N ratio for the original 16 amplifiers, which was given to be 46 dB, will be degraded (made worse) by 3 dB, and the C/N ratio for the total cascade of 32 units would be 43 dB.

We could use Figure 4-4 for this last problem also. If both 16 amplifier cascades had the same C/N ratio (46 dB), then the difference between the two ratios would be zero. We enter the chart in Figure 4-4 at 0 value on the bottom reference scale. This value, zero, happens to coincide with the left hand reference scale, so we read up vertically to where the reference data curve intersects the left hand scale, and the value given is 3 dB. We subtract 3 dB from the poorer C/N ratio (both are the same at 46 dB) and determine that the C/N ratio for the total cascade of 32 units would be 43 dB. This agrees with our earlier solution of this problem.

Application in System Engineering

We see that the C/N ratio is a function of both amplifier NF and input signal level. But once the equipment selection has been made, the NF is fixed and cannot be changed. We can, however, manipulate the C/N ratio by selecting the operating input signal levels.

An earlier example used an NF of 9 dB and an input level of +5 dBmV to produce a C/N ratio of 55 dB. If we raise the input signal level by 1 dB to +6 dBmV, and the NF remains unchanged at 9 dB, the amplifier would produce a C/N ratio of 56 dB. This can be verified by using the nomograph of Figure 4-2 or by the calculation

$$C/N = Sig_{in} + 59 - NF$$

$$= \underline{+5} + 59 - 9$$

$$= \underline{55\text{ dB}}$$

$$C/N = Sig_{in} + 59 - NF$$

$$= \underline{+6} + 59 - 9$$

$$= \underline{56\text{ dB}}$$

The above calculations develop the C/N ratio for a single amplifier, and show that to improve the C/N ratio by 1 dB the input signal level must be raised by 1 dB.

What happens in a cascade of several amplifiers?
The formula for determining the C/N ratio of any number of amplifiers in cascade when all have the same NF and all receive the same level input signals is

$$C/N_s = C/N_a - 10 \log N$$

where C/N_s = C/N ratio of the cascade of amplifiers

C/N_a = C/N ratio for a single amplifier

N = number of amplifiers in cascade

Our previous example produced a single amplifier C/N ratio of 55 dB with +5 dBmV of input, and a C/N ratio of 56 dB with +6 dBmV of input. Let us calculate the C/N ratio for a cascade of 25 amplifiers with both input levels:

$$C/N_s = C/N_a - 10 \log N \qquad C/N_s = C/N_a - 10 \log N$$

$$= \underline{55} - 10 \log 25 \qquad = \underline{56} - 10 \log 25$$

$$= \underline{41\ \text{dB}} \qquad = \underline{42\ \text{dB}}$$

The resultant system C/N ratios would be 41 dB and 42 dB respectively, clearly showing that raising all amplifier input levels by 1 dB did indeed raise and improve the system C/N ratio by 1 dB. Conversely, reducing all input levels 1 dB would degrade or reduce the system C/N ratio by 1 dB. Once this is clearly understood we may, in all subsequent system engineering, manipulate input signal levels with confidence that it will produce a predictable effect on end-of-system C/N ratio.

In addressing systems we may be required to calculate the composite C/N ratio of a cascade of amplifiers that are not identical, that may have different noise figures, and that may be operating with different input signal levels also. The technique required is to calculate the composite C/N ratio of individual strings or cascades of identical amplifiers separately, and then combine the resultant, different C/N ratios using the chart in Figure 4-4. Essentially this same technique must be used to combine the cable plant C/N ratio with the head end or signal origination installation C/N ratio.

Equipment Specifications

It is important that we understand how the individual amplifier specifications were developed or we may introduce serious error into system calculations. In most equipment we will be utilizing, the amplifier includes optional plug-in accessories as well as an actual gain producing module, as shown in Figure 4-5.

Most manufacturers specify the amplifier NF at the input to the gain module itself, since they cannot predict what plug-in units may be subsequently employed. If such a unit were equipped with optional equipment within the amplifier housing ahead of the gain module, the insertion loss of these items would produce an effective NF at the input cable connection to the housing itself that would be poorer than the NF specified for the module alone.

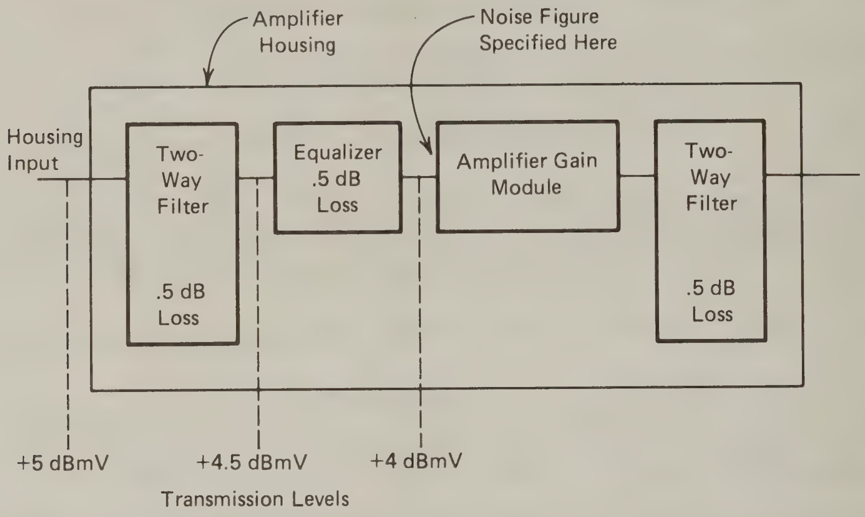

Amplifier Housing
Noise Figure Specified Here
Housing Input
Two-Way Filter .5 dB Loss
Equalizer .5 dB Loss
Amplifier Gain Module
Two-Way Filter .5 dB Loss
+5 dBmV
+4.5 dBmV
+4 dBmV
Transmission Levels

Figure 4-5 Noise Figure

This may become clearer if we examine the transmission levels shown in Figure 4-5. Assume we are presenting a +5 dBmV signal level at the input connector to the amplifier housing. This level is attenuated by both the two-way filter and by the cable equalizer such that the input level to the gain module itself is actually +4 dBmV. If the gain module had a specified 9 dB NF at its input connector, the C/N ratio produced would actually be 54 dB and not the 55 dB developed in our earlier example. Given a system cascade, the system C/N ratio would also be 1 dB poorer.

We must avoid such possible errors in developing system designs. If we had incorrectly assumed the 9 dB NF was presented at the housing input connector, we might design an entire system based on a +5 dBmV signal level at that point, but the actual end-of-system performance would have been a C/N ratio 1 dB poorer than our objective. Conversely, of course, if we want to produce a C/N ratio of 55 dB for each amplifier, we must lay out the system such that each amplifier housing input connector is fed signal at a +6 dBmV level, and not the +5 dBmV shown in the figure.

Before applying equipment specifications, one must be quite certain how they are defined.

If our initial design was for a system that would ultimately be equipped with two-way filters but these units were not installed initially, the transmission loss of the filters must be included in initial system noise calculations. If they were not, the desired system C/N ratio would be degraded when the filters were subsequently installed. We begin to see how the individual equipment specifications and the system operating levels must be reconciled by the system design engineer.

Equalization and C/N Ratio

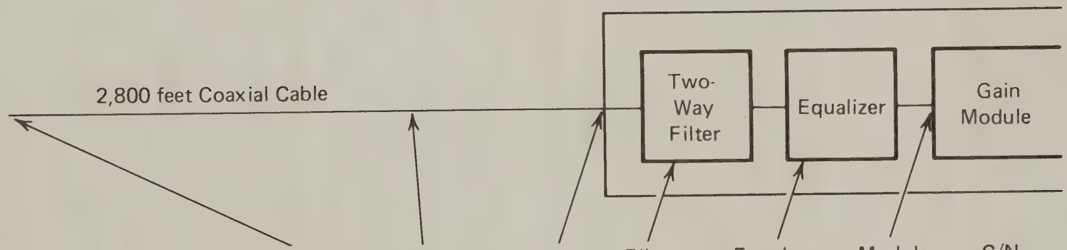
The noise produced in the input stages of an amplifier is essentially "flat" in nature; that is, it is at the same amplitude for all frequencies within the band of interest. Thus, the C/N ratio of an amplifier or a complete system of many amplifiers would be independent of the number of TV channels or carriers for other services transported by the system. This is only true if all carriers are presented to the amplifier input stages at equal amplitude. This requirement is by no means academic, since the coaxial cable itself presents different transmission loss characteristics at different transmission frequencies. If we are to protect equally the C/N ratio for all carriers transported, we must equalize the transmission levels in inverse proportion to the cable loss/frequency characteristics.

Perhaps this will be made clearer by examining Figure 4-6. Here we show a 2,800 foot length of .500 inch coaxial cable feeding an amplifier station. Note that for all three examples referenced, this cable exhibits substantially higher transmission loss at 211 MHz (Channel 13) than at 55 MHz (Channel 2). Example A in the figure shows the transmission levels when the length of cable is fed with both carriers at an equal amplitude of +40 dBmV. Here we are providing no equalization before the amplifier gain module at all, and as might be expected, there is a gross difference in the C/N ratio for both signals, which is clearly shown in the right hand column of the figure.

As the system was extended, if conditions were identical at all amplifiers in the system, we would eventually reach the point where Channel 13 was so noisy as to be unusable, but at that same point, Channel 2 would still be entirely satisfactory.

In Example B in the figure, the same input level relationship exists, equal amplitudes of +40 dBmV, but the equalizer insertion loss at both frequencies is sub-stantially different. The result is equal input levels to the gain module itself and, as to be expected, equal C/N ratios for both carriers.

This technique suffers some deficiency in system operations, however. Near the input to the system connecting coaxial cable section (left hand side of drawing), both signals are equal, and service-drop connections near this point would not be particularly difficult. But note that the signal level of both carriers at the input connector to the amplifier housing are substantially different by a matter of 16 dB (25 - 9 = 16). A subscriber connection tapped to the interconnecting cable for some distance ahead of the amplifier would be producing a substantial difference in the carrier levels presented to the subscriber service drop cable.


2,800 feet Coaxial Cable
Two-Way Filter
Equalizer
Gain Module

	Trans. Freq. (MHz)	Cable Input (dBmV)	Cable Loss (dB)	Hsing. Input (dBmV)	Filter Loss (dB)	Equal. Loss (dB)	Module Input (dBmV)	C/N Ratio (dB)
EXAMPLE A	55 (ch 2)	+ 40	15	+ 25	.5	0	+ 24.5	75.5
w/o amp equal flat sys input	211 (ch 13)	+ 40	31	+ 9	.5	0	+ 8.5	58.5
EXAMPLE B	55	+ 40	15	+ 25	.5	16.5	+ 8.0	58.0
with amp equal flat sys input	211	+ 40	31	+ 9	.5	.5	+ 8.0	58.0
EXAMPLE C	55	+ 32	15	+ 17	.5	8.5	+ 8.0	58.0
with amp equal tilted input	211	+ 40	31	+ 9	.5	.5	+ 8.0	58.0

Figure 4-6 Equalization and C/N Ratio

Assuming it were practical or convenient, we might adjust the signal levels (tilt them) at the output of the preceding device such that the input to the connecting coaxial cable might be as shown for Example C in the figure. The cable loss would of course remain as before, however, at any point along the connecting coaxial cable, the difference in signal level between the two carriers is no greater than 8 dB. The actual manner in which the "tilt" might be introduced in the output of the preceding amplifier will be covered in the next chapter when we discuss intermodulation distortion. Both Examples B and C in the figure protect the C/N ratio of both carriers equally, but C limits the variation in signal levels in the cable section.

Summary

We have seen how noise is introduced and accumulates in a system, and we understand that the selection of amplifier NF and the manipulation of input signal levels during system design are both factors in producing any specified C/N ratio at the end of a transmission system.

The transmission losses and levels used in the text are arbitrary for our purpose of example, and when we use the term "manipulate" as applied above to input signal levels, this would be the determination by selection of the output level of the preceding amplifier, loss of cable selected, and the spacing between amplifiers allowed. However, all of these factors are at the discretion of the system designer, who does have some latitude of choice on these items.

The cable distribution plant alone is, of course, not the only source of noise in an overall CATV system, and we will discuss this later in the text, but in designing, constructing, and maintaining the cable plant, we need logical interface points within the overall system and definite performance specifications between or within those interface points. Thus, we generate separate specifications for the cable plant alone that should be compatible with other noise sources when the entire system is considered, but that can be measured and demonstrated through the cable plant alone.

We have also seen that the critical amplifier specification relating to noise is not a complex factor at all, and is restricted to Noise Figure alone, which is independent of the number of signals passed through the amplifier. Given the NF, there is nothing else we really need to know about the input sections or stages of any amplifier or receiver in order to apply the unit effectively in any application.

Chapter 5

Intermodulation Distortion

Any amplifier will evidence some degree of non-linearity between the input signals applied to it and its output signals, and this non-linearity will introduce some degree of distortion to signals passed through the unit. Distortion might be defined as changes in a signal wave form introduced during its transmission through a circuit or device, i.e., the output wave form does not faithfully reproduce the input wave form. The more power passed through a unit, the less linear it will tend to be, consequently, the more pronounced the distortion it introduces will be.

Distortion as a System Phenomena

In wideband coaxial systems many RF signals are passed through a single amplifier stage, and the composite RF energy it is asked to handle can be quite significant. This is compounded by the fact that we require relatively high signal levels on each carrier at the output of each amplifier. Thus, the output stage of CATV amplifiers is susceptible to nonlinear operation, and will produce various undesirable effects called intermodulation (intermod) distortion. This effect takes several forms, but all are the result of several or many individual signals interacting with or on each other. An amplifier passing only one signal would produce no intermod, but this situation is purely academic for our purposes.

Since it is the output stage of an amplifier that is called upon to pass the highest levels of signals, then intermodulation distortion is primarily a concern of this part of an amplifier, and can be addressed completely independently of the C/N ratio, which was a function of the amplifier input stage only.

The amplifier introduces more intermod distortion when the output stage is required to handle higher levels of signal power. Then the distortion introduced will be proportional to the output level at which we operate the amplifier.

If we pass more signals through the unit, that raises the amount of power passed through the output stage, but distortion is also due to the interaction of several signals, and thus we experience higher intermod contributions when we are transmitting more signals through the unit.

When we addressed noise in an amplifier, it was not a complex problem, and we could adequately specify any amplifiers performance and "quality" by simply calling out a single parameter, Noise Figure. Intermod is more complex, and to define an amplifier's distortion characteristics we have to reference in some way not only the operating output level, but the number of signals (TV channels) that will be passed through it also.

The result of intermodulation distortion will be the generation of many spurious signals, as well as the transfer or superimposing of modulation (information) from one carrier on to another. At some level of amplitude, distortion will become visible as disturbing interference in a television picture. The specific level of visibility may be different for different forms of distortion, but the system designer is obliged to analyze the accumulation of distortion in its most offensive form, that is, that distortion that will become visible first in a particular system, and make certain that the unavoidable distortion that does accumulate remains well below the level of viewer perception.

Forms of intermodulation Distortion

One form of third order distortion is the transfer or superimposition of modulated information from one RF carrier to another, and this is called cross modulation, or X-Mod. X-Mod may be defined as the ratio, expressed in decibels, between interfering or unwanted video information and the desired video information that may be modulating the same carrier. More precisely perhaps, it is the ratio between the level of interfering video modulation with the level of 100 percent modulation of the carrier which would be what the desired video information is producing. It is generally expressed as a negative decibel ratio, but sometimes as a percentage.

Whenever more than one signal is passed through an amplifier, the output of that amplifier will include new signals at frequencies that were not present as input to the amplifier. In a form of distortion called Second Order Distortion, when two signals which we will call f_1 and f_2 pass through a nonlinear amplifier, at the output of the unit we will find the same two original signals (f_1 and f_2) and two new signals whose frequencies are the sum and difference of both the original signals. If either or both of these new spurious signals, sometimes called second order beats, happened to fall in the spectrum where we were trying to carry a television signal, it would be interfering, perhaps even to the extent of becoming visible.

A different form of distortion is called Triple Beat, and is evidenced as spurious signals that are generated within an amplifier when three or more carriers are passed through the unit. The spurious signals, referred to as triple beats, are sum and difference products of any three carriers.

Combinations of intermod distortion such as Composite Triple Beat are also generated, which represents the total number of beats that may appear (pile up) at or near a single frequency. Because of the high number of beats, if they are not phase coherent, the effect on transported video signals is similar to noise.

Intermodulation Distortion

It is not essential to our purpose of understanding coaxial transmission technology to pursue intermodulation distortion in greater depth, but we must remember that in a modern CATV system we may be transmitting as many as 50 or more individual signals. The number of potentially interfering beats that may be produced number in the hundreds. To some degree, all forms of distortion will be present when a multiplicity of signals are passed through an amplifier, and we need to understand how much we can tolerate, how it accumulates in a system, and how to restrict the accumulation to a tolerable level.

Generally one form of intermod distortion will be predominate or limiting in a particular system. That is, it will become visible before other forms do, and thus will demand remedial treatment before we would be required to address any other forms. It is generally accepted that for systems carrying more than 21 channels, composite triple beat (CTB) intermod will be limiting, but this line of demarcation is not definite or precise. In systems transporting only 21 channels or less, X-Mod will usually be the most discernible form of intermod.

All forms of intermodulation distortion build up in systems as the result of nonlinear amplifier characteristics, and all respond to the same remedial measure, thus, for purposes of our discussion, we could simply confine ourselves to a single form. Since X-Mod is somewhat more applicable for lightly loaded systems, we will make some calculations for X-Mod but it should be understood that this discussion and development of X-Mod will have similar implications for other forms of intermod. We will also make calculations for Composite Triple Beat for more heavily loaded examples.

Amplifier Output Level and X-Mod

Since the output stage of a CATV amplifier produces the major gain in the unit, the output stage is required to pass the highest levels of composite RF energy, and thus contributes almost all the X-Mod.

Contrary to our earlier development of noise in a system, with X-Mod we are concerned with the combining of discrete signals, thus we are adding signal voltages, not noise power. In Chapter 2 we learned that the formula for voltage ratios was

$$\text{dB} = 20 \log \frac{E_2}{E_1}$$

Thus, where a single dB amplifier input level change produced a single dB change in C/N ratio, with X-Mod, a single dB change in output level will produce a 2 dB change in X-Mod. Since X-Mod is a negative figure, improving X-Mod will produce a more negative figure, and degrading X-Mod will produce a less negative figure. X-Mod of -50 dB, for example, is more negative than -48 dB, and -50 dB X-Mod would be less offensive or disruptive than a higher level of only -48 dB.

In our earlier discussion on noise we introduced a nomograph (see Figure 3-2) which conveniently related the factors NF and input signal level to C/N ratio. This was possible because all amplifier noise figures are defined the same, and the nature of noise itself is characteristically the same in any portion of the transmission system spectrum. The factors involved were neither unique nor particularly complex. Such is not the case with X-Mod or with any other forms of intermod.

The ability of an individual amplifier to pass power may be unique to a particular design. A nomograph would only be applicable to a particular amplifier, and then only under a specific condition of channel loading. This is evident if we review manufacturer specifications on amplifiers. To adequately describe an amplifier's noise characteristics the manufacturer simply calls out a NF in decibels, and this needs no further reference or qualification. But in calling out X-Mod or other intermod performance, he must call out not only the amount of distortion produced but also reference the output signal level, which in turn must be qualified for the channel loading (number of RF carriers present).

There is general agreement in the CATV industry that -51 dB of X-Mod and -52 dB CTB represent acceptable levels of distortion in a system. But our discussion is not intended to establish performance specification, but to understand the phenomena of intermodulation as it accumulates in practical systems, and to master a methodology for calculating and limiting intermodulation distortion. We will not endorse any particular specification here, but the examples and explanations we present can be easily applied to comply with any system performance specification that the reader may encounter.

Amplifier Intermodulation Specifications

To calculate the X-Mod produced by a single amplifier, the formula is

$$XM_a = XM_{spec} + 2\,[OL_{oper} - OL_{spec}]$$

where XMa = single amplifier X-Mod in dB

XM_{spec} = Manufacturer specified X-Mod in dB

OL_{oper} = operating output signal level in dBmV

OL_{spec} = Manufacturer specified output level in dBmV

We need to know the value of these factors if we are to be able to apply the units efficiently. Then the equipment supplier must provide this information as a published equipment specification.

For example, an amplifier manufacturer might specify a unit's performance as follows:

	12 chans	21 chans	35 chans
Output Rating in dBmV (for -57 dB X-Mod)	+54.5	+52.5	+50.5

What does that mean?

The manufacturer has told us that if we use this unit in a twelve channel system carrying 12 TV signals, and if we operate the amplifier at +54.5 dBmV output signal level, the amplifier will generate -57 dB of X-Mod distortion. This same unit, used in a thirty-five channel system, must be operated at a lower output level, +50.5 dBmV to generate the same distortion level of -57 dB X-Mod.

Different amplifier manufacturers may specify their product in a different manner, but they still present all the necessary information. For example, a manufacturer might specify the identical unit we specified earlier as follows:

	12 chans	21 chans	35 chans
X-Mod in dB (at +34 dBmV output)	-98	-94	-90

What does that mean?

The manufacturer has told us that if we use this unit in a twelve channel system carrying 12 TV signals, and if we operate the amplifier at +34 dBmV output signal level, the amplifier will generate -98 dB of X-Mod distortion. This same unit, used in a thirty-five channel system, operated at a +34 dBmV output level will generate a distortion level of -90 dB X-Mod.

How can we reconcile these two apparently different specifications?

We stated earlier (in the Summary of Chapter 2) that a 1 dB change in amplifier output level would produce a 2 dB change in intermodulation distortion because it would be a voltage addition. If we accept this statement for the moment, then we can reconcile these specifications quite easily.

The second set of specifications stated that carrying twelve channels, if we operate at +34 dBmV output, the X-Mod would be -98 dB. The first set of specifications gave a -57 dB X-Mod distortion with an output level of +54.5 dBmV, carrying twelve channels.

What happens if we raise the output given in the first spec from +34 dBmV to + 54.5 dBmV? To raise the output to +54.5 dBmV, we have to raise the output by 54.5 -34 = 20.5 dB. For every dB increase in output level, we expect a 2 dB degradation in X=Mod. If we raise the output 20.5 dB, we would degrade X-Mod by twice that amount, or 41 dB, from 20.5 x 2 = 41. An X-Mod level of -98 dB degraded (made worse) by 41 dB would be -57 dB from 98 - 41 = 57. Note that this is exactly the X-Mod specified for a +54.5 dBmV output in the first specification.

To reinforce this point, we could take the output in the first specification (+54.5 dBmV) and reduce it to the +34 dBmV output given in the second specification. This reduces the output by 20.5 dB of course, and for every 1 dB reduction in output level, we expect the X-Mod to improve 2 dB. Then the X-Mod generated by the amplifier in the first specification would be improved by 41 dB (20.5 x 2 = 41) and would become dB from 57 +-98 dB from 57 + 41 = 98. Note this agrees exactly with the second specification.

Regardless how the amplifier specification is presented, the essential information is there and simply needs to be interpreted correctly.

Of course we are entirely free to operate at higher or lower output levels. If we operate at higher levels with the specified channel loadings, the X-Mod distortion will be at a higher level (more offensive and less negative in value), and if we operate at a lower output level, the X-Mod will be at a lower level (less offensive and more negative in value).

Is it possible that we might actually wish to operate at higher levels than those called out by the manufacturer? It certainly is possible, and in some cases, even probable. Of course increasing the operating output level will increase the X-Mod, but suppose we had a very limited cascade of amplifiers involved, as in a limited length Local Area Network (LAN) used for data within a single factory or building. The system length might be such that we can accept the increase in X-Mod and still meet transmission requirements satisfactorily.

Might we elect to operate below the manufacturers output figure? Yes.

Consider a very long cascade of units. By reducing the operating output level we would generate less X-Mod per amplifier, and thus less X-Mod at the end of the cascade also.

The amplifier operating levels given by the manufacturer serve only to clearly describe the amplifiers operating characteristics and performance. These levels need not be meticulously observed in every instance, and if we understand how they are developed and what they mean, we are perfectly free to operate at different levels. The important thing is that we do not and cannot violate the end-of-system specifications, that is, we must not compromise the system's transmission performance.

Broader Band Amplifier Specifications

In the amplifier specifications we presented above we restricted the specifications to 35 channel systems. In Figure 1-9 in Chapter 1 this is a 300 MHz system.

Why bother to even discuss such a limited bandwidth, in view of the fact that the state of the art today allows 450 or 500 MHz systems to be constructed?

Although wider bandwidth systems are certainly possible, in some instances they may not be economically practical. For example, in thinly populated rural areas or smaller communities, the supporting revenue base may be inadequate for a more expensive, broader band system. We might also find some application for limited bandwidth systems in smaller data networks, where additional transmission capacity is not a major consideration. We are obliged to address broader bandwidth systems, however, and in such cases, the CTB intermodulation distortion will usually be the most offensive. A typical broad band amplifier might be specified as follows:

Transmission Bandwidth	45 to 450 MHz
Operating Input Signal Level	+10 dBmV
Operating Output Signal Level	+31 dBmV
Composite Triple Beat (CTB)	-80 dB
Second Order Beat (f_1 + - f_2)	-83 dB
Cross Modulation (X-Mod)	-78 dB
Triple Beat (f_1 + - f_2 + - f_3)	-105 dB
Number of TV Channels	62

Note that just as in the earlier specifications, the manufacturer has presented all the information we require in that we have the channel loading (62), the output level (+31 dBmV), and the levels of the various forms of intermodulation that will be generated within the unit under these conditions.

We can process CTB in the same manner we did X-Mod earlier, that is, if we raise the operating output level by 1 dB we can expect the CTB to degrade 2 dB (voltage addition) from the specified -80 dB to -78 dB. Conversely, reducing the output level to +30 dBmV from +31 dBmV will improve the CTB from -80 dB to -82 dB. In all respects the amplifier behavior is the same as it was for X-Mod.

Calculating X-Mod

We have stated that increasing or decreasing output levels by 1 dB will introduce a 2 dB increase or decrease in X-Mod. Before we proceed any further, let us validate that statement mathematically. We will apply the first set of amplifier specifications from our previous example.

Carrying 12 channels at +40 dBmV output, X-Mod may be calculated as follows:

$$\begin{aligned} XM_a &= XM_{spec} + 2\,(OL_{oper} - OL_{spec}) \\ &= -57 + 2\,(40 - 54.5) \\ &= -86 \text{ dB X-Mod} \end{aligned}$$

If we raise the output level from +40 dBmV to +41 dBmV, the calculation is

$$XM_a = XM_{spec} + 2\,(OL_{oper} - OL_{spec})$$

$$= -57 + 2\,(41 - 54.5)$$

$$= -84 \text{ dB X-Mod}$$

We can clearly see that increasing output levels by 1 dB did in fact degrade X-Mod performance by 2 dB, since -84 dB is a poorer figure than -86 dB. Conversely, decreasing output levels by 1 dB would indeed improve X-Mod performance by 2 dB.

Understanding this relationship we can more conveniently apply published amplifier specifications without the need for any calculation. This simpler technique may also be helpful in applying X-Mod or CTB specifications that may be presented differently. Our original amplifier specification said the unit would produce a -57 dB X-Mod carrying 12 channels at an output level of +54.5 dBmV. If we operate this unit at +40 dBmV as is proposed, we will be operating 14.5 dB lower output than specified (54.5 -40 = 14.5). But since X-Mod decreases 2 dB for every 1 dB reduction in output level, the X-Mod at +40 dBmV output would be 29 dB better than specified (2 x 14.5 = 29). A 29 dB improvement in X-Mod from the specified -57 dB would be -86 dB from [(-57) + (-29) = -86]. Note this also agrees with the earlier calculation but we did not have to perform any complex calculation at all.

The purpose of this development was to reinforce the understanding of X-Mod and CTB and develop some facility at interpreting equipment specifications.

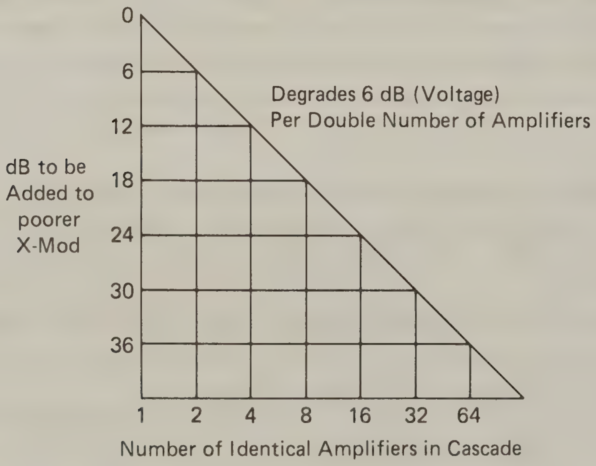


Figure 5-1 X-Mod and Amplifier Cascade

Combining Equal X-Mod Distortion

As we cascade amplifiers the intermod distortion will build up. In Figure 5-1 we can see the relationship between X-Mod and amplifier cascade, assuming, of course, identical X-Mod in all amplifiers. Note that when doubling the number of identical amplifiers, which would be combining or adding two equal X-Mods, the resultant X-Mod would be degraded by 6 dB. We can validate this statement mathematically. The formula for combining X-Mod is

$$XM_{sys} = XM_{amp} + 20 \log N$$

where XM_{sys} = system X-Mod in dB

XM_{amp} = amplifier X-Mod in dB

N = number of amplifiers in cascade

Assume an individual amplifier produces -86 dB X-Mod.
A cascade of 10 such amplifiers would produce

$$\begin{aligned} XM_{sys} &= XM_{amp} + 20 \log N \\ &= -86 + 20 \log 10 \\ &= -86 + 20 \\ &= \underline{-66\text{ dB}}\text{ Sys. X-Mod} \end{aligned}$$

A cascade of 20 such amplifiers would produce

$$\begin{aligned} XM_{sys} &= XM_{amp} + 20 \log 20 \\ &= -86 + (20 \times 1.3) \\ &= -86 + 26 \\ &= \underline{-60\text{ dB}}\text{ Sys. X-Mod} \end{aligned}$$

Note that the difference, 6 dB, agrees with our previous statement. We need not go through the calculation at all if the two X-Mods are equal, and the chart in Figure 4-1 shows the relationship of X-Mod to amplifier cascade. The note states that X-Mod degrades 6 dB when we double the number of identical amplifiers in a cascade. This is similar to the chart presented earlier for noise but not identical.

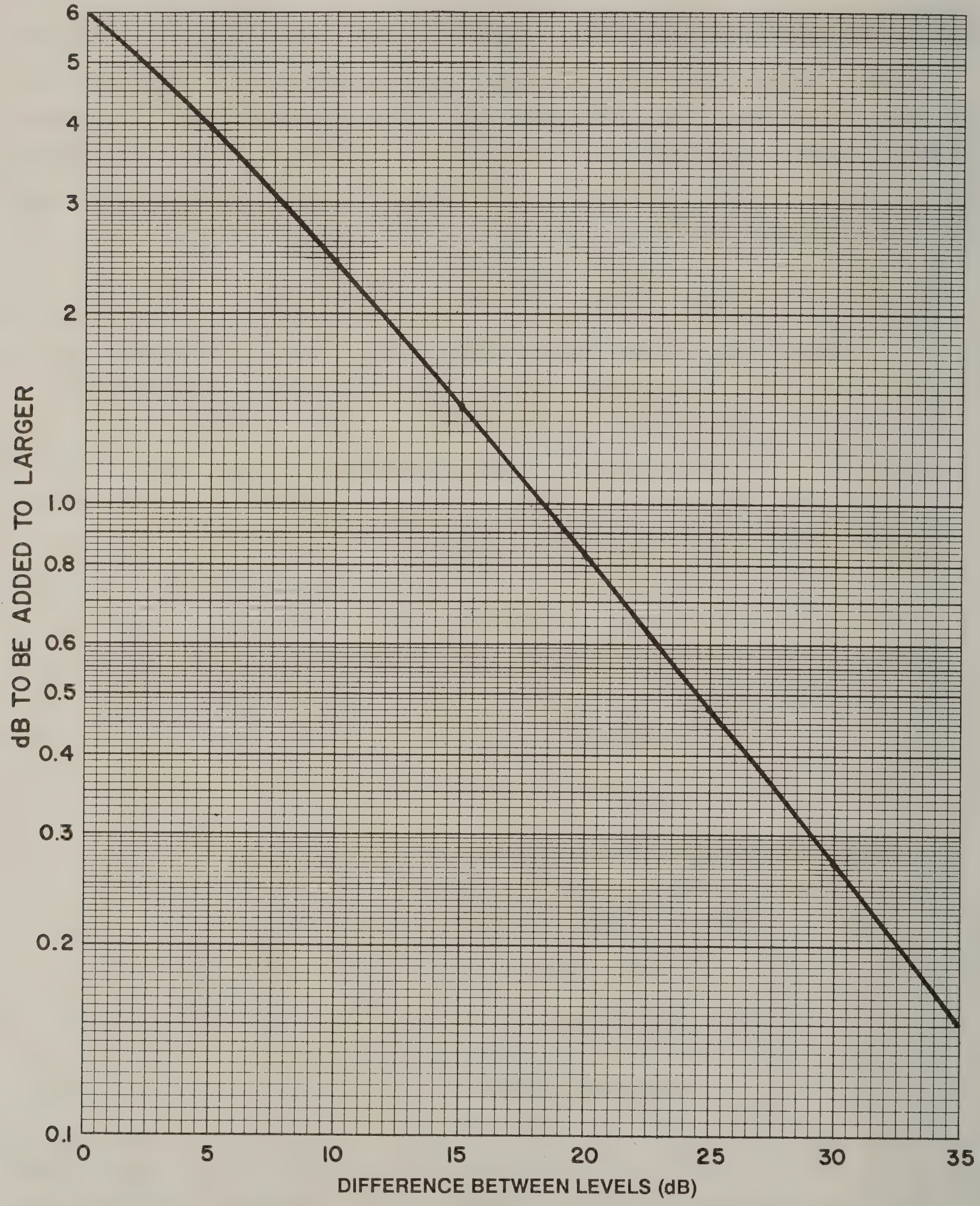


Figure 5-2 Combining Voltage (Intermod) Ratios

Combining Unequal X-Mod Distortion

If we are combining unequal X-Mod voltages it is possible to calculate the resultant X-Mod or, more conveniently, we could use the chart in Figure 5-2. This might be the case if we were adding five amplifiers to an existing cascade of 12 identical units, and all units had the same X-Mod. It would be equally applicable, however, if we were combining two separate cascades where the two X-Mods for each set of amplifiers were not the same.

Suppose we had 15 amplifiers in cascade and each unit had an X-Mod contribution of -83 dB. We want to extend the plant through three additional amplifiers, each generating -64 dB X-Mod. We can easily compute the X-Mod for each individual cascade as follows:

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= \underline{-83} + 20 \log \underline{15}$$

$$= \underline{-59.5 \text{ dB}} \text{ X-Mod}$$

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= \underline{-64} + 20 \log \underline{3}$$

$$= \underline{-54.5 \text{ dB}} \text{ X-Mod}$$

The difference between these is 5 dB. On the chart in Figure 5-2 we begin from the bottom margin where the dB reference is 5 dB and read up vertically until we find the diagonal reference data line. Then we read horizontally to the left margin which indicates we must add 3.9 dB to the poorest of the two X-Mods. Obviously -54.5 dB is a higher-level (poorer) X-Mod than -59.5 dB, and if we add 3.9 we find the resultant X-Mod is 50.6 dB for the total cascade of 18 amplifiers.

This particular example would be applicable in a trunk-plus-feeder type system design which we will discuss later. Keep in mind that the chart is equally useful in combining X-Mod or CTB regardless of the source, even if the X-Mod may be produced in other parts of a system than in the amplifiers. For example, if a microwave link were used to feed signals to a distribution cable system and the microwave link contributed X-Mod, it would be necessary to combine the microwave link X-Mod with the cable contributed X-Mod.

To determine the total X-Mod present at the worst-case or most distant subscriber station, it is often necessary to combine different X-Mod contributions. We have seen that if they are unequal values, the chart in Figure 5-2 makes this quite easy to determine. If more than two X-Mod contributions are involved, and they are not equal, the method is to simply combine any two first, using Figure 5-2, and then combine the resultant X-Mod with the remaining contribution.

A not uncommon example would be when a microwave link contributes X-Mod, a cascade of trunk amplifiers contributes a different X-Mod, and a cascade of line-extender amplifiers contributes yet another different value. Assume the microwave X-Mod was -82 dB and the trunk amplifiers alone produce -59.5 dB. Using Figure 5-2 we can combine these two and produce a -58.8 dB X-Mod.

But the line-extender amplifiers have not yet been considered. Suppose their X-Mod was -54.5 dB. We now must use Figure 5-2 and combine -54.5 with -58.8, resulting in a -50.7 dB X-Mod total for the system. Remember that although we used X-Mod, in a system carrying more than 21 channels, we could have done the same calculations except that CTB would be used.

Equalization and X-Mod

If we refer back to the previous chapter on noise, we can recall Example C in Figure 4-6, where we tilted the signal input (amplifier output) to the subsequent connecting coaxial cable section. We can now address the question of how we might produce a tilted amplifier output.

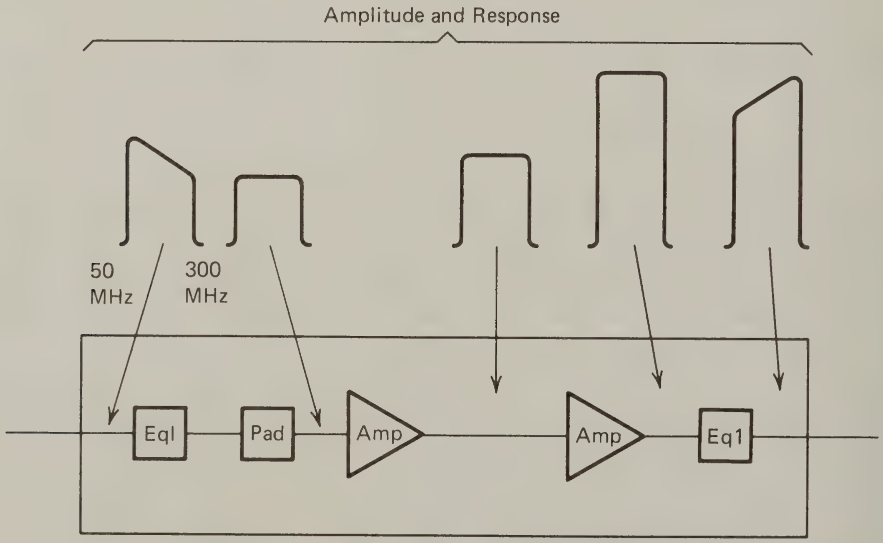


Figure 5-3 "Tilted" Amplifier Output

Examine the block diagram of the amplifier in Figure 5-3. Note that the gain module itself is identified as consisting of two distinctly different stages of gain.

This is actually how most units are supplied today even if they employ integrated circuit or hybrid chip construction. The input stage is designed for the best possible NF, since it is presented with relatively low input signal levels. This stage does not produce substantial gain, and thus we do not produce any significant intermodulation distortion in this stage. Given equal input signals, this unit preserves the best possible C/N ratio for all channels and provides sufficient gain to be able to effectively ignore the noise produced in the second or output amplifier stage. By providing interstage accessibility within the unit, variations of thermal or closed-loop AGC or ASC are also relatively easily accomplished.

The output stage of the amplifier provides a major increment of gain. Since its NF need not be a matter of concern the design can focus entirely on power-handling capability and linearity. Thus, the intermodulation distortion introduced can be held to relatively low levels. With this in mind, let us consider the question of tilted output levels.

Since the input cable equalizer shown in Figure 5-3 has already flattened out or equalized nearly all input signals to the same level of amplitude, we might simply pass all signals through both stages of amplification on a flat-response basis. Behind the output state in Figure 5-3 we have installed a pre-equalizer whose function is to pre-tilt the signals before applying them to the connecting coaxial plant. But with just a little thought we could see a way to produce that same tilt that would be more technically beneficial, and the method shown in Figure 5-3 for instructional purposes is not actually used.

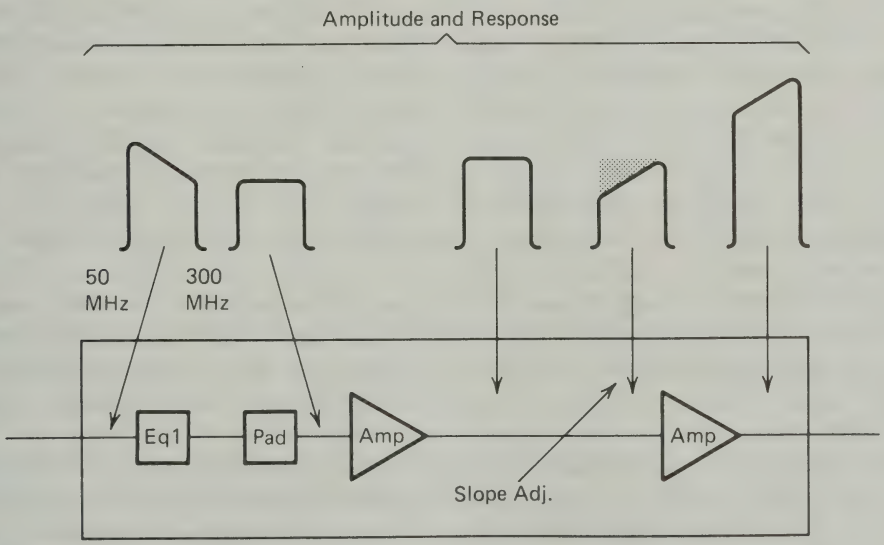


Figure 5-4 Interstage "Tilting"

If we tilted the signals in the interstage connection between input and output amplifiers we would have no adverse effect at all on the C/N ratio or gain required of the input amplifier stage. However, tilting before we pass through the output stage could significantly reduce the amount of RF energy passed through the output stage, substantially improving the intermodulation performance of the unit. This is shown in the frequency response curves for each transmission point within the amplifier housing in Figure 5-4.

This particular technique, or variations of it, is very widely (perhaps universally) employed in modern CATV systems. The shaded portion of the interstage response curve in Figure 5-4 represents RF energy that is not passed through the amplifier output stage.

Summary

The basic factors the system designer must consider regarding X-Mod or other forms of intermodulation distortion are channel loading, operating output levels, and specified amplifier output capability. Since the channel loading is almost always preestablished by system marketing or management considerations, and the output capability is a fixed constant once the equipment selection has been made, the only basic factor the designer may manipulate is system operating output levels.

There are techniques of both equipment design and system operation that will reduce the accumulation of X-Mod somewhat. For example, a push-pull design in amplifiers dramatically reduces second-order distortion buildup, and today second order is not generally considered to be limiting in system design. A technique of amplifier design called "feed forward" presents a very significant advantage in reducing intermod distortion, though it introduces a higher level of sophistication in the amplifiers themselves. Yet another technique of amplifier design is called "power doubling."

It is beyond the scope of this text to discuss individual amplifier designs in depth, but however superior the output capability of the units employed may be, the process of determining the intermodulation distortion that will accumulate in a system must still be followed, and the designer can only treat these units as higher grade devices, not as intermod free amplifiers.

By harmonically relating the carrier frequencies themselves it is also possible to improve system performance. This does not reduce the beats produced, but positions them within the system transmission spectrum such that they are more tolerable. In effect, all signal carriers are spaced precisely 6 MHz apart, thus all beats generated are at 6 MHz increments.

Since the television signals are vestigial sideband modulated, if the beat products can be manipulated to fall on or near the RF carriers themselves, they are much less offensive to the sideband video information. These refinements are somewhat beyond the scope of an introductory text such as this but are strongly recommended as worthy subjects for further study.

Chapter 6

Amplifier Gain

As our earlier discussion on noise demonstrated, the input signal levels to all amplifiers must be maintained at a sufficiently high level to protect the end-of-system C/N ratio. Equally important, the output levels must be held sufficiently low to ensure a tolerable end-of-system intermodulation distortion. The system designer must reconcile both of these factors with the economies of higher or lower gain amplifiers to produce satisfactory end-of-system performance in a cost effective manner.

Amplifier gain of itself imposes no restrictions on operating levels. We can operate a 22 dB gain unit at +10 dBmV input and produce +32 dBmV of output. We can also operate at +12 dBmV input and 22 dB of gain would produce a +34 dBmV output. Noise and intermod performance would, of course, be different under these different conditions.

Examining Different Operating Levels

To clearly demonstrate the relationship between loss and gain and the required consideration of X-Mod and noise, we will utilize a theoretical application. Assume that the transmission system originates at point A and that it must deliver signals to only one terminating location that we will call point B. We will consider the distance to point B as variable, so that we can examine the effects on system length of various combinations of gain and operational signal levels.

We will develop several examples, but in each case we will assume 62 channel loading, 450 MHz upper frequency limitation, and a cable loss of 1 dB per 100 feet. The following amplifier specification applies:

Transmission Bandwidth	45 to 450 MHz
Operating Input Level	+10 dBmV
Operating Output Level	+31 dBmV

Usable Gain	+21 dB
Composite Triple Beat (CTB)	-80 dB
Second Order Beat (f_1 + - f_2)	-83 dB
Cross Modulation (X-Mod)	-78 dB
Triple Beat (f_1 + - f_2 + - f_3)	-105 dB
Number of TV Channels	62
Noise Figure (NF)	9 dB

Let us compare a +10 dBmV input level with a +12 dBmV input level. Assuming a fixed gain of 22 dB, the respective output levels would be +31 and +33 dBmV.

At +10 dBmV input	At +12 dBmV input
$C/N = Sig_{in} + 59 - NF$	$C/N = Sig_{in} + 59 - NF$
$= +10 + 59 - 9$	$= +12 + 50 - 9$
$C/N = 60$ dB (per amplifier)	$C/N = 62$ dB (per amplifier)
A cascade of 20 amplifiers:	A cascade of 20 amplifiers:
$C/N = C/N_a - 10 \log N$	$C/N = C/N_a - 10 \log N$
$= 60 - 10 \log 20$	$= 62 - 10 \log 20$
$= 60 - 13$	$= 62 - 13$
$C/N = 47$ dB (per system)	$C/N = 49$ dB (per system)

We can examine CTB distortion for both operating levels quite easily. At +10 dBmV input with 21 dB gain, one amplifier is operating at +31 dBmV output. The amplifier specification stated that CTB would be -80 dB at +31 dBmV output. The second amplifier receives a +12 dBmV input and with 21 dB gain, will have a +33 dBmV output. This is 2 dB higher than the manufacturer specified output, so CTB will be 4 dB worse than the specified -80 dB, which is -76 dB at +33 dBmV output.

20 amps. at +31 dBmV out	20 amps. at +33 dBmV out
$CTB = CTB_a + 20 \log N$	$CTB = CTB_a + 20 \log N$
$= -80 + 20 \log 20$	$= -76 + 20 \log 20$
$CTB = -54$ dB (per system)	$CTB = -50$ dB (per system)

A comparison of these two 21 dB gain amplifiers shows:

Operating Levels	System C/N	System CTB
+10 in / +31 out	47 dB	-54 dB
+12 in / +33 out	49 dB	-50 dB

Note that, as expected, raising input by 2 dB improved the C/N ratio by 2 dB, and raising output by 2 dB degraded CTB by 4 dB. Since both cases used identical amplifier gain (21 dB) and the same cable loss (1dB/100 feet), the length of each system of 20 amplifiers would be the same, about 7.95 miles (2,100 x 20 = 42,000 feet).

We already knew that changing operating levels would impact on end-of-system performance, and we can see that the operating levels might be selected to favor either noise or intermod, if there were compelling reasons to do so. But the significant thing to note here is that, even though we manipulated the levels, we cannot improve the economics of the system. We had only 21 dB of usable gain available for both cases. We utilized it fully in both cases, and the amplifier spacing was not increased at all. To improve the economics in both cases the designer could only reduce the number of amplifiers required by either using a higher gain amplifier (longer amplifier spacing) or a more expensive lower loss cable (fewer amplifiers required).

However, this example did not consider any end-of-system performance requirements. Perhaps there may be an advantage to either lower or higher operating levels in some instances.

Operating Levels versus System Specifications

Let us arbitrarily establish a system C/N ratio specification of 43 dB and a system CTB specification of -52 dB. Using the same amplifier and cable, we can try to find out if operating levels have any impact on system length or "reach."

At +10 in / +31 out operating levels, each amplifier produced a C/N of 60 dB and contributed -80 dB CTB distortion. Both of these are much better than the system specifications demand. At 60 dB C/N per amplifier, we can actually construct a cascade of 50 amplifiers before the system C/N ratio would degrade to 43 dB, which is all that the specifications require.

At -80 dB CTB per amplifier, however, a cascade of 50 units would produce -46 dB CTB. This is not compliant with the requirement of -52 dB.

If we operate the identical units at +8.5 dBmV input which, with 21 dB gain, would produce a +29.5 dBmV output, we can transmit through a cascade of 35 amplifiers and still make system specifications from:

At +10 dBmV input C/N per amplifier was 60 dB. Then at +8.5 dBmV input C/N per amplifier is 58.5 dB. A cascade of 35 such units would produce a system C/N of

$$\begin{aligned} C/N &= C/N_a - 10 \log N \\ &= 58.5 - 10 \log 35 \\ &= 58.5 - 15.44 \\ &= 43 \text{ dB } C/N \text{ system} \end{aligned}$$

At +31 dBmV output CTB was -80 dB. At +8.5 input, 21 dB of gain produces +29.5 dBmV output, and the CTB per amplifier would be -83 dB. Then 35 such units would produce system CTB of

$$\begin{aligned} CTB &= CTB_a + 20 \log N \\ &= -83 + 20 \log 35 \\ &= -83 + 31 \\ &= -52 \text{ dB CTB system} \end{aligned}$$

By operating at signal levels other than those recommended by the manufacturer, we can increase the overall length of a system, while still observing the specified performance requirements. The significance of this is that if, as we assumed back at the beginning of this discussion, the requirement was only to transmit signals between two discrete points, then simply by manipulating operating levels, with no change in equipment or cable loss, we could extend the length of the system.

Then why was the manufacturer so specific about the recommended operating levels?

Because, as we shall see in a subsequent chapter of the text, the amplifier was intended for use in a particular system configuration where, at the end of the amplifier cascade, it was desirable to have CTB performance that was significantly better than the specifications required, but the C/N performance was not required to be substantially better than the specification.

Given an amplifier gain of 21 dB and cable loss of 1 dB per 100 feet, a cascade of 35 amplifiers would be a system 73,500 feet in length, or 13.9 miles.

Comparing Different Gain Amplifiers

There are applications that may not require such heavy traffic loading (62 television channels) such as smaller, rural CATV systems or Local Area Networks carrying data or telecommunications services. To really understand coaxial technology perhaps we ought to address such an application. We will assume a 21 channel system is required.

Let us compare two distinctly different amplifiers. We will use a 22 dB gain unit and compare it to a 32 dB gain unit. The amplifier specifications are as follows:

	Amplifier A	Amplifier B
Usable gain (spacing)	22 dB	32 dB
Noise Figure	10 dB	10 dB
Output capability (21 chans. for -57 dB X-Mod)	+50 dBmV	+48 dBmV

Note that amplifier B has a poorer output capability for the same X-Mod output. If we use the previous cable loss figure (1 dB/100 feet), 32 dB spacing is 3,200 feet.

If we had a cascade of 25 type A amplifiers, we would have a system 10.4 miles long, which is a pretty realistic application. With 32 dB spacing, 10.4 miles would require only 17.2 amplifiers, which we will round off to 18 units. We will operate amplifier A at +11 input / +33 output and amplifier B at +6 input / +38 output.

With 25 type A amplifiers in cascade, performance will be:

$C/N = C/N_a - 10 \log N$ $\qquad$ $XM = XM_a + 20 \log N$

$= 60 - 10 \log 25$ $\qquad$ $= -91 + 20 \log 25$

$C/N = 46$ dB system $\qquad$ $XM = -63$ dB system

With 18 type B amplifiers in cascade, performance will be:

$C/N = C/N_a - 10 \log N$ $\qquad$ $XM = XM_a + 20 \log N$

$= 55 - 10 \log 18$ $\qquad$ $= -77 + 20 \log 18$

$C/N = 42.4$ dB system $\qquad$ $XM = 52$ dB system

Using amplifier A we produce a system C/N ratio of 46 dB and X-Mod of -63 dB. Both of these are far better than the system specifications require (42 dB C/N ratio and -52 dB X-Mod).

Using amplifier B we produce a system C/N ratio of 42.4 dB and X-Mod of -52 dB. Both are fully compliant with system specifications, but with amplifier B we have reduced the number of amplifiers from 25 to 18. Note we cannot extend the system using amplifier B operating at these levels without imposing out-of-specification performance, but we were only required to go 10.4 miles. We have accomplished that and did produce compliant end-of-system performance.

Although amplifier B specification on X-Mod is poorer than amplifier A, it is quite adequate for our application. The economy of using seven fewer amplifiers includes reducing the power required for the system, and reducing the long-term maintenance costs, as well as the initial capital investment requirements, and surely 18 amplifiers might be considered more reliable than 25.

Relationship of Gain, Noise, and Intermod

Let us review what we have learned so far. The relationship of noise and intermod to input and output levels is well established. We know that operating levels can be manipulated, and why we might wish to manipulate them, and we see that no amount of manipulation alone will alter system cost. We can perhaps extend system "reach" by selecting operating levels, but the equivalent unit cost of the plant is not reduced by such changes.

However, using higher gain amplifiers can have a significant effect on system cost, since we delivered compliant performance at the required distance using fewer amplifiers. But we cannot simply go to higher gain indiscriminately even though the economics are attractive. Higher gain eventually presents penalties of either noise or intermod accumulation in the system.

As a general rule, a lower gain unit will always provide the longest possible cascade of amplifiers and will produce the highest quality of transmission for a given length system. It will always require more amplifiers, however, which is a cost penalty not only in initial system construction but in long-term system operation and maintenance as well. Our examples were intended to demonstrate the selection process considering both amplifier gain and system operating levels.

Super-trunk Systems

In the previous chapter we introduced the term "super-trunk." We define this as cable plant designed and constructed purely to transport signals from one point (perhaps the head end) to a second point (a distribution hub location) only. No signal distribution or service tapping is required en route.

In this chapter, for demonstration purposes, we addressed signal transportation from point A to point B with no extension beyond point B at all. This was helpful in making our comparisons and examples but might easily be misconstrued. A super-trunk application is quite different.

Super-trunk, by definition, will be feeding signals into some local distribution cable plant. Although the super-trunk is, at first glance, a logical candidate for higher gain amplifiers simply because it usually involves a significant transmission distance, this is not really the case. Higher gain implies either lower input signals (and poorer C/N ratios) or higher output signals (and greater intermod) or both. Since the super-trunk will be followed by a substantial contribution of both noise and intermod from the local cable plant, it must be very conservatively designed.

The noise and intermod from the super-trunk will be combined with that from the local plant. Thus, the super-trunk itself must produce high transmission quality.

Trunk-plus-Feeder Systems

There are some rather complex and subtle economic factors involved that our examples do not really call out very well. Consider the conventional trunk-plus-feeder designs almost universally employed in urban CATV systems today. Typically, such systems have a cascade of trunk amplifiers intentionally limited in length to perhaps 20 or 25 units maximum. All of these trunk amplifiers are relatively low gain (22 to 26 dB perhaps), operating with conservatively low output levels. One might think that this would be a very practical situation in which to use fewer but higher gain amplifiers. However, the restriction on output level, and consequently on amplifier gain, is by no means accidental in these cases.

These systems might be characterized as high density, imposing very heavy tap loading of the plant. By that we mean service-drop tap requirements are frequent, and rather evenly distributed throughout the service area. Under these conditions the efficiency of tapping can be substantially improved if operating signals are kept at a high level throughout the feeder cable plant (that portion of the cable plant that is directly tapped for service drops). But maintaining high levels in the feeder cables requires high operating output levels in all feeder amplifiers. As we already know, high output levels introduce high intermod.

To make the high feeder plant distortion tolerable, the trunk plant is operated at low output levels, thus introducing relatively low distortion. The economic advantages of high signal level, high distortion feeder are so persuasive that the system accepts the high cost of low signal level, low distortion trunk. In this instance the basic economic argument for high gain amplifiers is much more complicated than simply reducing the number of amplifiers required, as we did in our examples.

In the next chapter we will discuss the elective distribution of noise and intermod within a system, and the urban, trunk/feeder systems are the classic example of this. The basic relationships shown in our examples are perfectly valid, but do not reflect all the economic complexities of actual, operating CATV systems. Later in the text our discussion on urban design philosophy will develop this in greater depth.

Single Cable Rural Systems

The rural applications, with more widely distributed and thinner population, are very much like the examples we have used here. In such cases, since there is no cluster of service points at the end of the cable system, we can logically assume the most distant subscriber location to be the point B we used in our examples, and simply address the entire system as a single cable utilizing a sequence or cascade of identical amplifiers. This may also be the case in some Local Area Networks, and later in the text we will discuss both types of systems in greater depth.

Equipment Specifications

It is important that we understand how the individual equipment specifications were developed or we may introduce serious error into system calculations. In most equipment we will be utilizing, the amplifier includes optional plug-in accessories as well as an actual gain producing module, as shown in Figure 6-1. Most manufacturers specify gain between the input and output ports of the gain module alone. The housing and plug-in accessories might be used with any of several different gain modules.

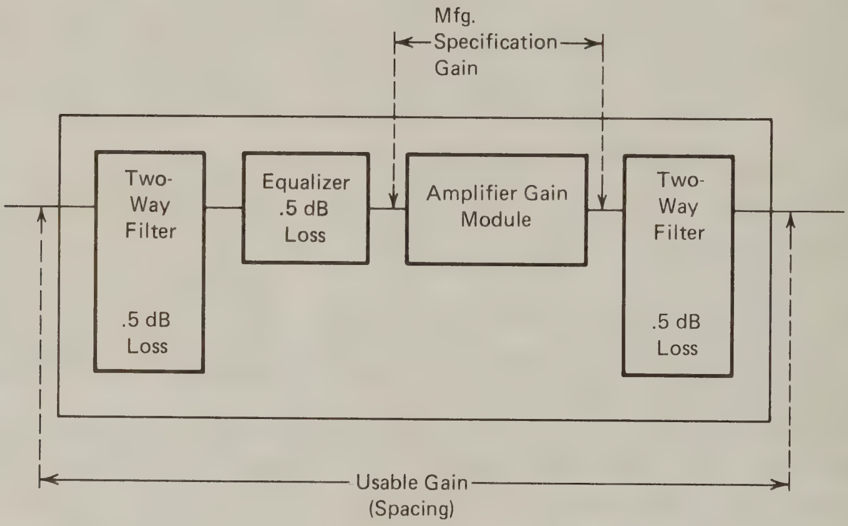


Figure 6-1 Amplifier Gain

However, when we discuss amplifier gain, or apply it in system design work, we are talking about the gain available between the housing input and output ports. Quite obviously this figure will be lower due to the insertion loss of the various accessories involved. Thus when we discuss 22 dB spacing, we are talking about the gain available between the housing ports. We called this usable gain. But the gain module itself may well have provided 24 or 26 dB of gain.

It is important that we completely understand how the manufacturer specifies gain for his equipment. And if we are designing for future two-way service (requiring filters, of course), we must calculate on the basis of the filter loss being inserted, even though the filters themselves may not be inserted initially. Noise and intermod calculations must reflect actual gain module input and output levels.

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Summary

The selection of amplifier gain is greatly influenced by system economics, but must always be considered from the point of view of transmission performance. If the system designer can identify his particular requirement as to system length and distribution of load points (subscriber service taps), he can select the most cost-effective compromise between gain and operating signal levels. A particular combination of these two factors will be most efficient for a particular situation or application, but it by no means follows that the same combination will be optimal for all applications.

The system designer is free to evaluate these different factors, indeed for cost reduction purposes he is obliged to do so, providing he does not violate end-of-system transmission specifications. The final selection of system operating levels and amplifier gain must consider overall system configuration (other system elements) and possible ultimate system extensions. Designs which do not do this may be fully compliant when initially constructed, but might impose out-of-specification performance at some future time.

When operational signal levels and amplifier gain have been finalized, the designer must address the questions of 'tilted operation," system frequency response, equalization, etc., but these are fairly straightforward and, in any event, cannot be addressed before the basic selections we mention here have been resolved.

Chapter 7

Noise and Intermodulation in System Design

In the preceding chapters we have discussed at some length both noise and intermod. Later we will discuss several system design philosophies in depth. But before proceeding further, an overview of noise and intermod may provide some practical application of what we have learned so far, and will emphasize the importance of these two factors as they impact on both system designs and operation of systems.

Transmission Quality

In the final analysis it is the quality of transmission through the system that is important, not only the quality initially established by system design, but the quality that can realistically be maintained over long periods (years) of system operation. That quality is clearly identified in CATV systems as a minimum or total absence of visible impairment in the television pictures transported.

There are other factors that can and may introduce visible interference in TV pictures, for example, echoes or reflections in the transmission system or AC hum modulation. We will discuss these later on, but the most probable cause of picture degradation (visible interference) in CATV systems will be noise and intermod.

In the long-term operation of systems, many variable factors can and will work toward the gradual erosion of transmission quality. Changes in temperature, for example, which cause changes in cable loss is one consideration. Even the replacement of inoperative equipment that may introduce inadvertent variations in operational signal levels can degrade transmission quality, and over an extended period of time many such replacements may be involved.

A thorough understanding of noise and intermod, and their relationship to operational signal levels, is essential. When we discuss thermal system control it will be necessary to immediately recognize the effects on both noise and intermod. We cannot overemphasize the need to be completely familiar with both of these terms.

System Elements

We can identify several different elements in a CATV system. For example, the head end "off-air" signal acquisition and processing equipments would be one distinct element. A satellite receiving installation would be another. A microwave link or super-trunk facility involved in feeding a distant distributing cable plant would be a separate, identifiable element. Even within the cable plant itself we may have clearly different elements such as a trunk system followed by a feeder sub-system.

As we pass signals through the different elements they all make their individual contributions of noise and X-Mod. Due to the nature of each, they may individually contribute more of one than the other, but in considering the overall end-of-system performance we must recognize and include all element contributions. Given an overall performance specification for both noise and X-Mod we can readily measure end-of-system performance at the most distant subscriber terminal. As system noise accumulates from all elements, not just the cable plant itself, at some point it will reach a level that becomes intolerable and visible in television pictures. This is equally true of X-Mod.

However, some of the elements in a system are more susceptible to variations in transmission performance than others. The head end equipment, for example, is usually designed with a wide dynamic range and excellent AGC and is much less subject to wide variations in temperature. Thus, the signal quality as delivered from the head end is more stable and predictable. The cable plant itself, on the other hand, is subject to many variables such as temperature, power source voltage fluctuations, and even improper adjustments by maintenance personnel. If we are to preserve the quality of transmission through the entire system, we must provide some reasonable margins for variation. And obviously, those elements of the system most subject to variation need the most margin for error.

In our earlier discussions of both noise and X-Mod we clearly saw their relationship to input and output signal levels. The long-term maintenance of these levels within reasonably close tolerances is then essential throughout the cable plant. And if we provide some margin of tolerance in our system design, it should equally protect input levels (C/N ratio) and output levels (X-Mod). Once the gain of an amplifier has been established by selection during the system design process, any variation of input levels will have an impact (perhaps reduced by automatic control capability but an impact nevertheless) on output levels.

Since we will be experiencing some conditions of variation that will tend to increase all system levels (colder temperatures) and other conditions that will tend to decrease all system levels (warmer temperatures), we need to provide equal margins of protection for both. Note that this does not necessarily mean that every single element in a system needs to be equally protected. For example, if the "off-air" element inherently produces substantial noise but very little X-Mod, as it normally would, balance between noise and X-Mod would not be a consideration in specifications for that element.

Perhaps this can be made clearer if we examine Figure 7-1. Here we show a single point of program acquisition (head end) with some distribution cable (system A) fed directly from this head end. We are also extending signals over a microwave link to a second distribution cable plant (system B). The interconnecting feeder link might also have been provided by a super-trunk cable system. The individual elements in the system in Figure 7-1 can be identified as follows:

1. Head end
2. Cable system A
3. Cable system B
4. Microwave link

Note that the head end includes two different signal sources, and each will utilize different signal-processing equipment. There may also be additional signal sources such as locally originated television signals. These various signal sources may also have different noise or intermod contributions. However, for purposes of system analysis or design, we can assume the worst case noise contribution (C/N ratio) of all the head end signals as being the C/N ratio for the head end itself. Since head end signal processing is generally done on individual signals through single-channel equipments, no significant intermod distortion is produced.

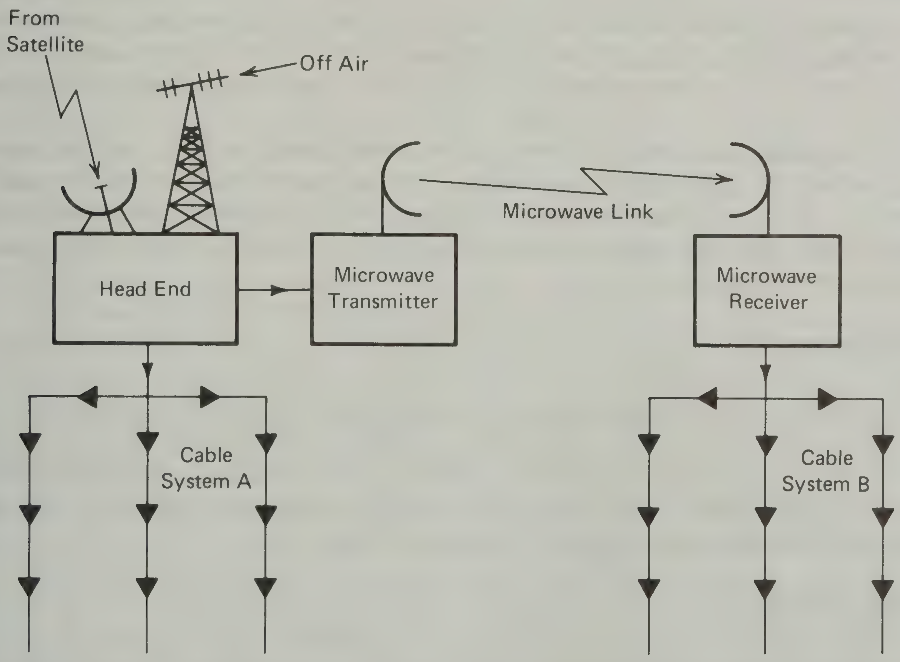


Figure 7-1 System Elements

If we specify performance for each individual system element, we can establish practical interface points with the overall system. We can subsequently measure and evaluate the performance of any single element alone. This of course greatly simplifies the overall design problem. With clearly identified specifications for the cable plant alone the cable system design is easier to develop. But the individual element specifications must all be compatible with the overall or end-of-system performance requirements.

Table 7-A Noise and Intermod Distribution

System Element	C/N Ratio (dB)	X-Mod (dB)
Head End	53	N/A
Cable System A	43	-52
Cable System B	43	-52
Microwave Link	53	-82

For purposes of this discussion let us arbitrarily assign performance specifications to each element in the system presented in Figure 7-1. These figures should not be considered as standards or recommendations but were selected for illustrative purposes only.

It is evident that the overall system performance (most distant subscriber station served) will reflect the accumulation or buildup of both noise and X-Mod from all of these elements. It is also clear that cable system B will incur noise and X-Mod from the microwave link but cable system A will not. Then we can calculate end-of-system performance for both systems.

System A Performance

By using the chart for combining C/N ratios (Figure 4-4), we can combine the C/N ratios of the head end and for the cable plant in system A. The result is a C/N ratio of 42.6 dB overall through system A. Since we introduced no significant X-Mod in the head end, the X-Mod from the cable plant in system A is effectively the end-of-system X-Mod performance, a figure of -52 dB (from Table 7-A).

System B Performance

By using the chart for C/N ratios (Figure 4-4) we can combine the C/N ratios of the system elements.

Note that in System B we have three elements to consider, (head end, microwave link, and cable plant). We could combine any two and then combine the resultant C/N ratio with the remaining C/N ratio. But note that both the head end and the microwave link have identical C/N ratios of 53 dB. We learned in Chapter 4 that combining equal C/N ratios degraded the overall C/N ratio by 3 dB. Thus, we do not need to use the chart at all to determine that the combination of head end and microwave link will produce a C/N ratio of 50 dB.

We can use the chart (Figure 4-4) to combine this figure, 50 dB C/N ratio, with the 43 dB C/N ratio of system B cable plant. The end-of-system C/N ratio will be 42.2 dB. Since the head end X-Mod can be ignored, we need only combine the X-Mod from the microwave link (-82 dB) and the cable plant (-52 dB). Using the chart for combining X-Mod (Figure 5-2), an end-of-system X-Mod for cable system B of -51.7 dB will be produced.

General Discussion

Note that system A produced a C/N ratio of 42.6 dB with X-Mod at -52 dB. System B produced a C/N ratio of 42.2 dB with X-Mod at -51.7 dB. The difference between the two systems is not very large but it is present. If we think about this for a moment, we realize that in combining either the C/N ratio or X-Mod if the difference between the two figures being combined is large, the impact or change on the poorer figure is small. Head end processing or microwave links present substantially better C/N ratio and X-Mod performance; thus, the cable plant is usually the major source of both in actual systems.

This would also be true if we were adding only one amplifier to an existing cascade of say 20 identical amplifiers. The X-Mod and noise introduced by a single amplifier would be so small relative to the C/N ratio and X-Mod of the 20-unit cascade that its impact on end-of-system performance would be minimal.

Consider for a moment if the system shown in Figure 7-1 had used a super-trunk cable plant as an interconnecting link rather than the relatively low-noise, low-intermod microwave system. If the super-trunk had required a very substantial cascade, say 15 amplifiers, we would have to address the design of the super-trunk quite carefully. To minimize the super-trunk C/N ratio and X-Mod contribution might take a very conservative design, or it might impose a more conservative (probably more expensive) design throughout cable system B distribution plant.

The purpose of this discussion is to reinforce our understanding of noise and X-Mod as they apply in actual systems. For example, it is sound practice, generally applied, to design head ends such that their C/N ratio is at least 10 dB better than the cable plant they feed. Understanding noise and X-Mod will also help in operating systems. If, for example, subscriber trouble reports indicate X-Mod is building up in a system (windshield wiper effects on TV screens, for example), the trouble is most probably not at the head end at all. If reports are of snow or noise in only one channel, it's a good bet that the problem is not in the cable plant.

Cumulative Degradation

In Figure 7-2 we show graphically how system performance will inevitably degrade as a function of cable plant length (amplifiers in cascade). Within the distribution plant itself we cannot change the rate at which the transmission quality will degrade. Doubling the number of amplifiers will always degrade C/N ratio by 3 dB and X-Mod by 6 dB, but by judicious selection of input and output levels, we can establish the level of quality from which the degradation subsequently detracts.

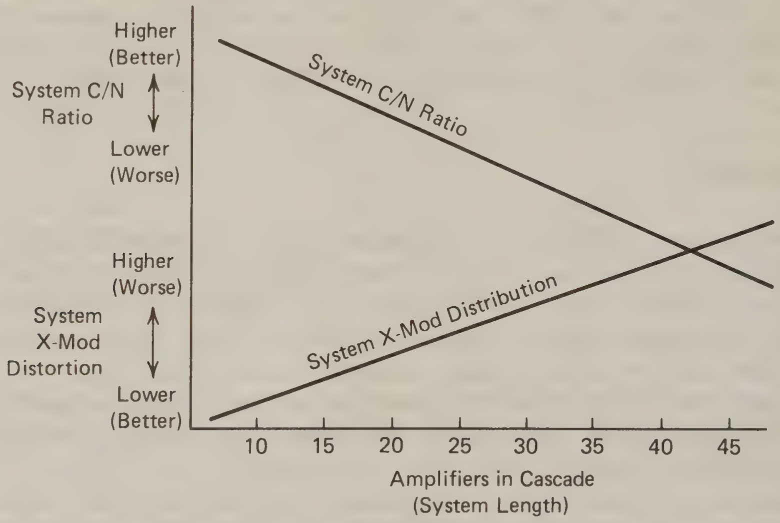


Figure 7-2 Noise and Intermodulation

If the choice of amplifier NF and input signal level is such that all amplifiers in the system produce a C/N ratio of 59 dB, then two amplifiers produce 56 dB; 4, 53 dB; 8, 50 dB; 16, 47 dB; 32, 44 dB; and 64, 41 dB. If the choice of amplifier NF and input signal level is such that all amplifiers in the system produce a C/N ratio of only 53 dB, then two amplifiers produce 50 dB; 4, 47 dB; 8, 44 dB; and 16, 41 dB. A similar development can be made for X-Mod distortion. We can manipulate transmission levels (input and output) to provide system extensions of the required length and still meet end-of-system specifications.

X-Mod and Noise in Cable Plant Design

We have established that system performance specifications for both noise and X-Mod can and must be determined for the distribution cable plant itself; however, in our tutorial developments of both C/N ratio and X-Mod, we used a single cable route.

We also assumed only one type of amplifier to show the accumulation or buildup of both noise and X-Mod. In actual systems we are not constrained to one type of amplifier or one set of input/output signal levels. We may, if it were advantageous to do so, distribute the total allowable noise and the total allowable X-Mod in any manner we wish within the cable plant. The only restriction is that, for whatever reason, any distribution cannot produce end-of-system performance not in compliance with our cable plant specifications.

Later in the text we will present different system design philosophies that distribute the noise and distortion differently to best serve different applications, but simply to demonstrate the point, we will give a purely theoretical example of distribution here. Assume a cascade of 30 amplifiers. Further assume that the cable plant performance specifications were 43 dB C/N ratio and -53 dB X-Mod. If each amplifier had an NF of 9 dB and we operated all amplifiers at +8 dBmV of input, the end-of-system C/N ratio would be calculated as follows:

$$C/N = Sig_{in} + 59 - NF - 10 \log N$$

$$= 8 + 59 - 9 - 10 \log 30$$

$$= 43.2 \text{ dB C/N system}$$

But if we operated 15 amplifiers at +7 dBmV input and 15 at +9 dBmV input, what would be the end-of-system C/N ratio? At +7 dBmV of input

$$C/N = Sig_{in} + 59 - NF$$

$$= 7 + 59 - 9$$

$$= 57 \text{ dB (per amplifier)}$$

A cascade of 15 such amplifiers would produce a C/N ratio of

$$C/N = C/N_a - 10 \log N$$

$$= 57 - 10 \log 15$$

$$= 45.2 \text{ dB (per cascade)}$$

At +9 dBmV input the individual amplifier C/N would be

$$C/N = Sig_{in} + 59 - NF$$

$$= 9 + 59 - 9$$

$$= 59 \text{ dB (per amplifier)}$$

A cascade of 15 such amplifiers would produce a C/N ratio of

$$C/N = C/N_a - 10 \log N$$

$$= 59 - 10 \log 15$$

$$= 47.2 \text{ dB (per cascade)}$$

Combining these two ratios would give an overall C/N ratio of 43.0 dB. This agrees very closely with our previous calculation, that produced 43.2 dB (system).

We could develop a similar redistribution of X-Mod by manipulating output levels only. This example may not seem to have any practical application but it is useful in that it demonstrates the freedom of action available to the system designer, providing that he observes the rules and does not compromise end-of-system specifications. From our later discussions we will better understand the potentialities of redistributing noise or intermod.

Summary

We can clearly see that the specifications for distribution cable plant alone cannot be established without some regard for overall system design. The modifications or changes in the cable plant specification may or may not be significant depending on the other system elements but they must be examined and considered. With a basic understanding of input and output levels and their impact on system noise and X-Mod, we can proceed to the next logical consideration of amplifier gain.

However, to firmly establish the general rules of noise and X-Mod, the following review is presented:

1. Single-amplifier C/N ratio changes 1 dB up or down for every 1 dB change in input signal level.
2. System C/N ratio changes 1 dB up or down for every 1 dB change in input signal levels if all amplifier input levels are changed by that same amount.
3. Combining two equal C/N ratios degrades the resultant C/N ratio by 3 dB.
4. Doubling the number of identical amplifiers in a cascade produces two equal C/N ratios, and thus degrades the resultant C/N ratio by 3 dB.
5. Any number of equal or unequal C/N ratios may be combined to establish an overall or total C/N ratio.
6. Single-amplifier X-Mod changes 2 dB up or down for every 1 dB change in output signal levels.
7. System X-Mod changes 2 dB up or down for every 1 dB change in output signal levels, if all amplifier output levels are changed by that same amount.
8. Combining two equal X-Mod ratios degrades the resultant X-Mod by 6 dB.

Chapter 8

Coaxial Cable and Reflections

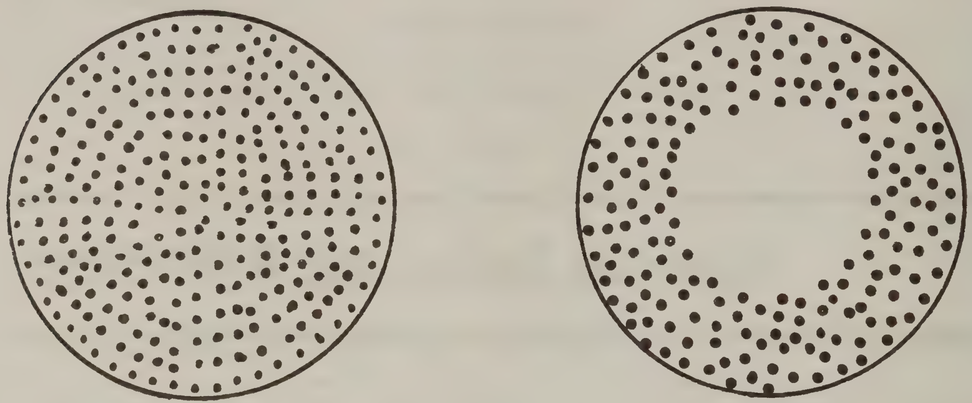
A coaxial cable may be defined as two metallic conductors that share the same axis and are separated by a dielectric (non-conducting) material.

Skin Effect

When alternating current flows through a metallic conductor, a phenomenon known as "skin effect" occurs. More electrons flow through the conductor in the area near the outer surface of the conductor than flow through the center of the conductor. This is a different phenomenon than with direct current where electrons tend to flow with equal ease throughout the entire conducting area. This phenomenon is shown in Figure 8-1. At higher alternating current frequencies, at RF for example, and at the frequencies that we encounter in CATV systems, the "skin effect" becomes more pronounced.

In DC applications, if we increase the size of a conductor and thus provide a larger area for electron flow, the resistance of the conductor is reduced. This same condition is experienced with alternating currents, that is, a larger size conductor introduces less transmission loss but the "skin effect" makes transmission loss a frequency sensitive factor.

At higher AC frequencies, more electrons flow nearer the outer surface of the conductor. The end effect is to introduce greater transmission loss at higher frequencies since this effectively reduces the cross section that actually carries the electron flow. This accounts for transmission losses being higher at higher AC frequencies, the square root of frequency loss factor that we experience in CATV systems. A rough estimate of the difference in loss would be that 216 MHz (Channel 13) will be attenuated about twice as much as 54 MHz (Channel 2) when both are passed through the same coaxial cable.



Direct Current

Alternating Current
(Skin Effect)

Figure 8-1 Electron Flow in a Conductor

Characteristic Impedance

All transmission lines have a characteristic impedance whether they are metallic twisted pairs in a telephone cable, open wire conductors on a pole line, or coaxial cables. The characteristic impedance of coaxial cable is a function of the ratio of the diameter of the inner conductor to the diameter of the outer conductor.

The nature of the dielectric itself is a factor in establishing the characteristic impedance of coaxial cables. The term K factor is used to define the Dielectric Constant of any dielectric material. Some coaxial cables utilize air as the dielectric, and air has a dielectric constant of 1.0. Other cables employ solid poly materials that have a dielectric constant of 2.3, and some cables use a poly material but foam the material with air or an inert gas, reducing the dielectric constant to 1.5 or so.

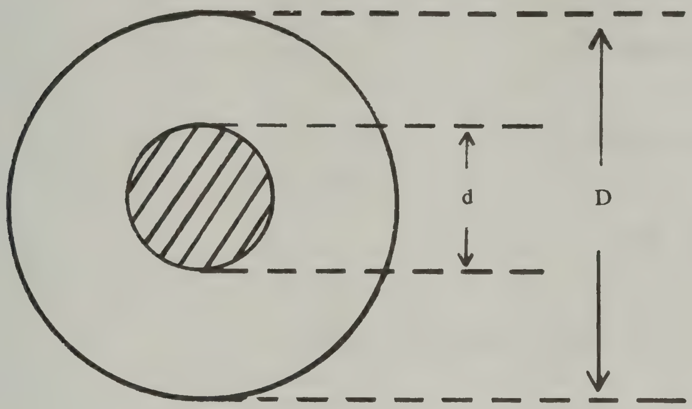
The formula to determine the characteristic impedance of an air dielectric coaxial cable is

$$Z = 138 \log \frac{D}{d}$$

where Z = Cable characteristic impedance in ohms

D = Diameter of outer conductor (Fig. 8-2)

d = Diameter of inner conductor (Fig. 8-2)



For Air Dielectric

$$Z = 138 \log D/d$$

For Other Dielectric

$$Z = 138 \log \frac{D/d}{\sqrt{K}}$$

Figure 8-2 Characteristic Impedance

We can manufacture coaxial cable in many different sizes, but if we maintain the proper ratio between the conductor diameters, they could all have the same characteristic impedance regardless of overall cable dimensions.

Example 1: When D = 3.49", d = 1.0", and K = 1.0, what is Z?

$$Z = 138 \log \frac{D/d}{\sqrt{K}}$$

$$= 138 \times \log \frac{\frac{3.49}{1.0}}{\sqrt{1.0}}$$

$$= 138 \times \log \frac{3.49}{1.0}$$

$$= 138 \times \log 3.49$$

$$= 138 \times 0.5428$$

$$= 74.9 \text{ ohms}$$

Example 2: When $D = 0.349''$, $d = 0.1''$, and $K = 1.0$, what is Z?

$$Z = 138 \times \log \frac{.349/0.1}{\sqrt{1.0}}$$

$$= 138 \times \log \frac{0.349}{0.1}$$

$$= 138 \times \log .349$$

$$= 138 \times 0.05428$$

$$= 74.9 \text{ ohms}$$

Example 3: When $D = 1.745''$, $d = 0.5''$, and $K = 1.0$, what is Z?

$$Z = 138 \times \log \frac{1.745/0.5}{\sqrt{1.0}}$$

$$= 138 \times \log \frac{1.745}{0.5}$$

$$= 138 \times \log 3.49$$

$$= 138 \times 0.5428$$

$$= 74.9 \text{ ohms}$$

Example 4: When D = 3.49", d = 0.5", and K = 1.0, what is Z?

$$Z = 138 \times \log \frac{3.49/0.5}{\sqrt{0.1}}$$

$$= 138 \times \log \frac{3.49}{0.5}$$

$$= 138 \times \log 6.98$$

$$= 138 \times 0.8438$$

$$= 116.45 \text{ ohms}$$

The cables in Examples 1, 2, and 3 are all different in size but all have a characteristic impedance of 75 ohms, or very nearly so. In Example 4 we used the same dimension for the diameter of the center conductor that we used in Example 3 (0.5") but we used a larger dimension for the outer conductor diameter (3.49"). Note that the characteristic impedance in this case was 116 ohms, or very nearly so.

Example 5: When D = 0.75", d = 0.175", and K = 1.5, what is Z?

$$Z = 138 \times \log \frac{0.75/0.175}{\sqrt{1.5}}$$

$$= 138 \times \log \frac{4.2857}{1.2247}$$

$$= 138 \times \log 3.4993$$

$$= 138 \times 0.54398$$

$$= 75.1 \text{ ohms}$$

In Example 5 we used a foamed dielectric cable with a dielectric constant of 1.5 and produced a 75 ohm impedance.

If we increase the center conductor size alone and do not increase the outer conductor diameter, the center conductor resistance would be smaller, reducing the transmission loss, but the characteristic impedance of the cable gets smaller.

Coaxial Cable Transmission Loss

From Ohm's Law, as we learned in Chapter 2, power equals the current squared times the resistance ($P=I^2R$). If we had the same amount of power to pass through a cable, what would be the impact of different characteristic impedances of two cables?

$P = I^2 Z$	$P = I^2 Z$
if $P = 5$	if $P = 5$
$Z = 100$	$Z = 50$
Then $I = .2236$	Then $I = .3162$

Note that the power in both of these calculations is the same but we must pass more current through the smaller resistance (lower impedance) to transmit the same amount of power. If we reduce the center conductor size but do not reduce the outer conductor diameter, the center conductor resistance would be larger and the transmission loss would be increased, but the characteristic impedance of the cable would get larger. From Ohm's Law, this would require less current to flow for the same amount of power to be transmitted, as we see in the calculation above.

It appears then that a higher characteristic impedance would always be most efficient for our purposes, but when we reduced the size of the center conductor, we reduced the area for electron flow and the area for the "skin effect" current flow also. By increasing the resistance we have increased the transmission loss of the cable. This increase in cable loss tends to offset the advantage of higher cable impedance.

In CATV systems we are transporting very low levels of power but we expect to encounter rather long lengths of coaxial cable. We would prefer to compromise power carrying capability in favor of reduced transmission loss, and this can be done. The optimum relationship between characteristic impedance and conductor resistance for low transmission loss works out to be any ratio between outer and inner conductor size that produces a 75 ohm cable impedance, regardless of cable size. This is the reason all CATV systems use 75 ohm cable, because this minimizes transmission losses at the frequencies we intend to transmit.

Of course we can increase both the inner and outer conductor sizes, still maintaining the optimum ratio and still preserving a 75 ohm characteristic impedance. If we do so, cable losses will be reduced but the larger size cable will require more material and will cost more money.

The nature of the dielectric material used to separate the two conductors also has an impact on the attenuation (loss) of the cable as well as on the characteristic impedance. For cables using the same dielectric material (same dielectric constant), we can increase both the inner conductor and outer conductor diameters and still maintain the same ratio, thus maintaining the same characteristic impedance just as we can with air dielectric cables.

There are other applications for coaxial cable that may be better served with a different characteristic impedance. Cables are designed with different impedances just for these applications. If, for example, we needed to optimize the breakdown voltage characteristic, a 60 ohm impedance would be best. For power carrying capability, 33 ohms is most effective. Figure 8-3 shows the performance characteristics of coaxial cables having different characteristic impedances than 75 ohms.

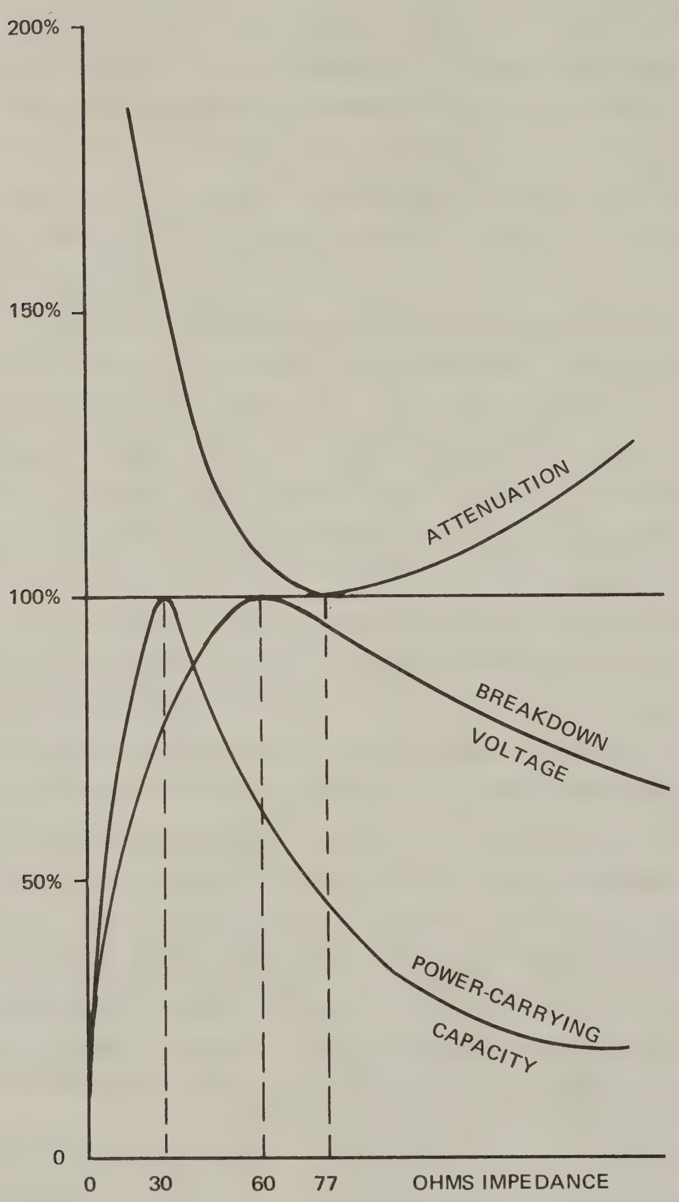


Figure 8-3 Coaxial Cable Characteristics

Typical transmission losses for several foam dielectric coaxial cable sizes in general use today are shown in Table 8-A.

Table 8-A Foam Dielectric cable loss (dB per 100 ft)

Cable Size (cable OD)	Loss at 54 MHz	Loss at 500 MHz
1.16 inch	0.23	0.77
1.00 inch	0.31	0.97
.875 inch	0.33	1.05
.840 inch	0.30	1.05
.750 inch	0.37	1.17
.625 inch	0.46	1.40
.565 inch	0.44	1.51
.500 inch	0.54	1.70
.412 inch	0.67	2.15
RG 6	1.60	4.60
RG 59	2.05	5.65

Impedance Matching

The transfer of energy between devices such as amplifiers or couplers, etc., and into and out of the interconnecting cable itself, is most efficient when the device impedance matches that of the cable. Since 75 ohms is an optimum cable impedance for transmission loss, it follows logically that all devices should be designed for 75 ohm impedance also, and they are.

Due to the mechanical structure of coaxial cables it is relatively easy to maintain a constant impedance throughout the entire length of the cable, however, the frequent introduction of other devices such as amplifiers and taps introduces problems. The simple transition from a coaxial structure to a circuit board and discrete components makes some degree of impedance mismatch at such interfaces inevitable.

When an impedance mismatch is introduced into a system, some of the signal energy that is propagating through the system is reflected from the irregularity. Reflections are also introduced by gross irregularities such as unterminated ends of cables or breaks in the electrical continuity of the cable outer conductor. The visible effect of reflections is similar to the familiar "ghosting" produced by multi-path signal reception of broadcast signals although cable system reflections are not usually as pronounced.

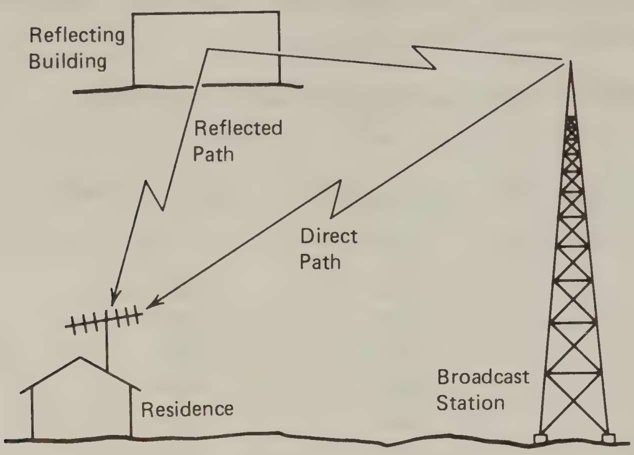


Figure 8-4 Multi-path Reception

The signal that is received at the residence antenna as a result of the reflected signal path has farther to travel than the direct path signal, so the reflected signal arrives at the receiver later since it takes longer to get there. Depending on the amplitude and time delay of the reflected signal, the television receiver will display the signal on the screen as a second image displaced horizontally on the screen from the same image that was received earlier. How offensive the reflection is to the viewer depends upon the delay and the amplitude difference between the two pictures. In both multi-path and cable system reflections, the desired signal is always present, and it is the reflected signal that we must be concerned with.

When the reflected energy is confined to only part of the spectrum occupied by the television signal, it is called an echo, and will only affect part of the picture or the sound, or the color sub-carrier. If the reflected energy substantially covers the frequency spectrum occupied by the television signal, it is called a reflection and will be apparent as an entire reproduction of the television picture.

How is such a signal generated and how might it build up in cable systems?

Return Loss

For purposes of measurement and reference, return loss, another term for reflection coefficient or Voltage Standing Wave Ratio (VSWR) stated in decibels, has been introduced. It refers to the energy level reflected from a discontinuity or mismatch. When the energy reflected by a discontinuity is minimal, the return loss will be numerically large. Although the designers of amplifiers and other devices take pains to match the impedance of the unit carefully to the cable itself, some impedance mismatch is inevitable. In the manufacturing of coaxial cable itself, periodic mechanical discontinuities are introduced that are mismatches. This is referred to as cable structural return loss and is also specified in dB.

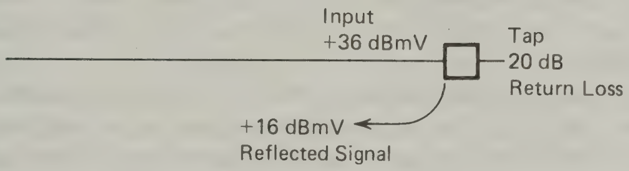

Input
+36 dBmV
Tap
20 dB
Return Loss
+16 dBmV
Reflected Signal

Figure 8-5 Return Loss

In Figure 8-5 we show a device, in this instance a tap, connected to the end of a coaxial cable. The device is specified by the manufacturer to have a 20 dB return loss. An RF signal, at +36 dBmV level, is applied to the input of the unit. If the return loss of the device were 0 dB, 100 percent of the applied RF energy would have been reflected and the Voltage Standing Wave Ratio would be infinity. If the return loss is 20 dB, as in this case, the reflection coefficient would be 10 percent and the Voltage Standing Wave Ratio would be 1.222.

Put more simply, any signal presented to the input of the device will produce a reflection whose amplitude will be 20 dB down from the level of the original input signal. This reflection will propagate back up the cable just as if it were a desirable signal launched into that end of the cable. In our example in Figure 8-5 the reflected signal level is shown to be +16 dBmV, 20 dB lower than the input level of +36 dBmV.

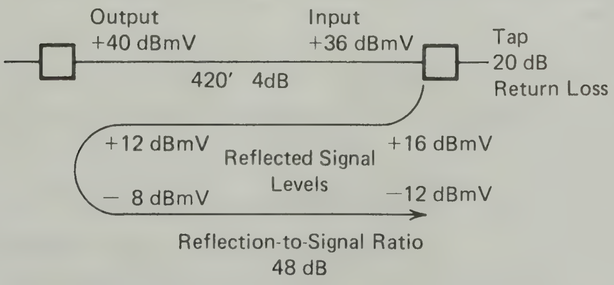

Output
+40 dBmV
Input
+36 dBmV
Tap
20 dB
Return Loss
420′ 4dB
+12 dBmV
Reflected Signal
Levels
+16 dBmV
− 8 dBmV
−12 dBmV
Reflection-to-Signal Ratio
48 dB

Figure 8-6 Reflection-to-Signal Ratio

The discontinuities introduced into coaxial cable during the manufacturing processes are purely mechanical and are relatively easy to control. Thus higher return loss figures for cable are normal, usually on the order of 30 dB or so. Amplifiers are generally poorest at 16 or 18 dB, and most passive devices are specified as 20 dB or better. All devices have return loss specified for both input and output connections. The worst-case return loss is always specified. Cable called out to have 30 dB return loss may very well have substantially better performance at some frequencies. This is also true of other devices.

Figure 8-6 shows two taps separated by 420 ft. of cable that has a total transmission loss of 4 dB. Both devices are specified to have input and output return loss of 20 dB. Given a +40 dBmV input to the cable section, the level of the reflected signal is shown at several points. Since the return loss is 20 dB for both ports of both devices, each reflection point reduces the reflection level by that same amount. In this example we are assuming the worst-case return loss applies and we will ignore frequency for the moment.

With 4 dB cable loss, the input to the second tap is +36 dBmV. The reflected signal is 20 dB down from that at +16 dBmV. The reflected energy propagates back up the cable, incurring 4 dB of loss in the process, and is presented to the output port of the first tap at +12 dBmV. There is a 20 dB loss (return loss), and the reflection leaves this point at -8 dBmV. It is presented to the input of the second tap at -12 dBmV. Since the original signal level at this same point (input to tap 2) was +36 dBmV, the reflection-to-signal (R/S) ratio is 48 dB.

This relationship (ratio) would be the same whatever the original signal level. For example, given a +30 dBmV input to the cable section, the reflection level at the input to tap 2 would be 48 dB lower, or -18 dBmV.

The level of the reflected signal in relationship to the original signal as they are both presented to a television receiver, has a great deal to do with how perceptible the reflection will be on the TV screen. It is obvious that a high return loss figure for all devices is most desirable and will reduce the level of the potentially offending reflections, however, the spacing, and thus the cable attenuation, is also a factor.

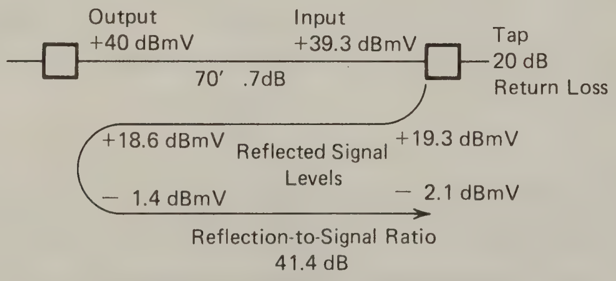


Figure 8-7 Short Spacing

Consider Figure 8-7 where the physical spacing between taps is given as 70 feet, which we will assume to have 0.7 dB of loss. The input to the cable section remains +40 dBmV as before, and each tap has a 20 dB return loss. However, if we duplicate the previous calculations using the lower cable loss (0.7 dB), the reflection signal level applied to the input of tap 2 becomes -2.1 dB. The original signal at that same point was +39.3 dBmV. The difference between these two levels, the R/S ratio, is now 41.4 dB, not our previous 48 dB.

Since nothing else was changed, the shorter spacing and lower cable loss obviously produce a less satisfactory ratio (higher level reflected signal). We might expect shorter spacing between taps in towns and cities where houses are close together and almost every pole has a tap. In both of these examples, if one of the devices had been an amplifier with a lower return loss specification, the amplitude of the reflected signal would have been higher still. Of course, if the return loss of both taps had been higher, the R/S ratio would also have been better. We can clearly see the relationship of specified return loss of devices and physical spacing as they both influence the amplitude of the reflections. However, the problem is a bit more complex than that.

Time Delay and Reflections

If a delayed signal is presented to a television receiver along with the original signal, the delay is evidenced in a horizontal displacement of the delayed picture. The TV set "paints" the original picture and then paints the second picture also, but the second picture is moved slightly to the right on the screen. Even if both signals were of equal amplitude, if the delay time were very short, the horizontal displacement on the TV screen would be very small and the reflection would not be perceptible to the viewer. Both signals would be detected and displayed but they would not be displaced enough to appear as two separate pictures.

This may be more easily understood if we consider a horizontal line on a television screen as the unit of time it takes for the electron beam to travel from the left-hand side of the screen to the right-hand side. The the North American standards for frame rate, interlacing, and horizontal scanning frequency are such that a single line, exclusive of blanking and synchronization information, is 52.5 microseconds.

If we determine the time delay imposed on the reflected signal, it can be transposed to a percentage of the single line time (52.5 microseconds) and directly related to a percentage of the physical screen width where the time delay will displace the reflected signal. For example, a delay of 0.2 microseconds would be 0.4 percent of 52.5 microseconds, and on a 25 inch picture tube this delay would displace the reflection from the original picture by approximately 0.1 of an inch.

In considering reflections and their effect on picture quality, we must consider both the amplitude of the reflected signal in relationship to the original signal, and the time delay between the reflected signal and the original picture information. When the reflection is across the entire video spectrum equally, or nearly so, there will be a complete reproduction of the original picture. If the discontinuity is such that the reflection is only part of the video spectrum, it will produce an effect on the screen called "ringing" or "smearing."

Generally, the reflection or echo is weaker (lower in amplitude) than the original signal, and when more than one reflection is present, one pattern will usually predominate visually and the others will be relatively inoffensive. When the reflection can be clearly distinguished from the primary image (significantly delayed in time), the degree of impairment in picture display will be largely dictated by the amplitude of the reflected signal. If the delay time is small, even higher amplitude reflections will be unobtrusive. The nature of the video information itself has quite a bit to do with how much delay can be tolerated by the viewer. For example, alpha-numeric information will exaggerate a reflection much more than a sweeping scenery shot taken outdoors.

The three factors, video information, echo amplitude, and time delay, are difficult to relate mathematically and as a practical matter have been evaluated largely on the basis of experience and observation. The initial establishment of noise standards for television pictures were developed on much the same basis, using subjective viewer testing programs. It has been shown in studies not presented here that echoes that are delayed 500 nanoseconds, down 30 dB from the original signal level, are perceptible to average viewers. Echoes delayed 500 nanoseconds and down only 20 dB in level can be annoying to some viewers.

Reflections in Operating Systems

If there were only a single reflection to consider, as in our earlier example with two taps, the problem is quite straightforward and the return loss provided by the devices would allow us to simply ignore the reflected signal in most practical cable systems, however, we wish to insert many passive devices into long cable routes.

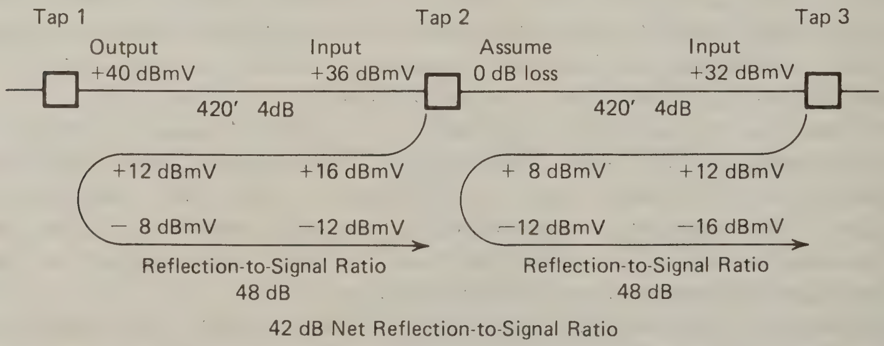

Tap 1
Tap 2
Tap 3
Output
+40 dBmV
Input
+36 dBmV
Assume
0 dB loss
Input
+32 dBmV
420′ 4dB
420′ 4dB
+12 dBmV
+16 dBmV
+ 8 dBmV
+12 dBmV
− 8 dBmV
−12 dBmV
−12 dBmV
−16 dBmV
Reflection-to-Signal Ratio
48 dB
Reflection-to-Signal Ratio
48 dB
42 dB Net Reflection-to-Signal Ratio

Figure 8-8 Two Taps

In Figure 8-6 it is evident that the reflected signal, having passed down the cable once, back up and then down the cable again, had a longer transmission path to negotiate than the original signal and took quite a bit longer to arrive at it's destination (the input port of tap 2). Depending on just how long the transmission path was in terms of wavelengths will determine the phase shift imparted to the reflected signal as it is presented to tap 2.

Let us consider Figure 8-8 where we have added a 420-foot cable and a third tap. We will assume the spacing is precisely identical (420 feet), that tap 2 has 0 dB insertion loss, and that all three taps have 20 dB return loss at both input and output ports. To simplify the example, we will apply +40 dBmV from the output of tap 1 as we did earlier. The conditions are exactly as in Figure 8-6 and the level of the reflected signal at the input to tap 2 would be -12 dBmV as shown.

The input level to tap 3, for the original signal, will now be +32 dBmV. Since cable losses and return losses between taps 2 and 3 are identical with those between taps 1 and 2, we know the reflected signal applied to tap 3 input will be 48 dB down from the original signal applied to this same point. This would be 32 - 48 or -16 dBmV.

Note that both cable spans have a R/S ratio of 48 dB. From our earlier studies we know that if we combine equal voltage ratios, this will impose a 6 dB change in the net effective ratio for the combination. For in-phase (additive) reflections this could lower or degrade the R/S ratio by 6 dB or it might improve the R/S ratio for out-of-phase (cancelling) reflections, but these calculations assume precisely identical phase shift for either case. This would be the worst-case condition for additive reflections, and in the case of cancelling, it is unlikely that complete cancellation would actually be achieved.

In Figure 8-6 we saw that a single reflection generated between taps 420 ft. apart provide an R/S ratio of 48 dB. An identical reflection (identical spacing) located anywhere farther down the system would produce an identical 48 dB ratio and would be in phase and additive with the first reflected signal. This would degrade the ratio of the combination by 6 dB and the net ratio would be 42 dB, substantially poorer than either of the two individual ratios.

What is the significance of this in operating systems?

System Considerations

Since we may be considering many reflections from many different points in a system, and since the signal levels at these points may vary considerably, it is much more practical to consider the ratio of reflection to signal level than the actual amplitude of the reflected signal. As we have seen, the ratio is independent of the amplitude. In Figure 8-8 the two reflections involved were shown to have identical ratios of 48 dB. Combining ratios is quite simple, and we assumed the reflections were in phase and additive, so the combined or net ratio was given to be 42 dB. But how would these two reflections actually interact in a real system?

If the two signals both incurred identical delay they would be in phase with each other and the net R/S ratio of 42 dB is correct. For the reflections to be in phase, the transmission delay between both would have to be an even multiple of a half-wavelength in both cases. If one transmission delay (spacing) differed from the other by a quarter-wavelength, the reflections would be out of phase and some cancellation would occur. Obviously, when we are involved with wavelength the addition or cancellation is related to a specific frequency.

Velocity of Propagation

The velocity of propagation of radio waves in air is the same as the velocity of light (186,000 miles per second or 3 x 10^8 meters per second). We can quite easily calculate a wavelength since this is the distance a wave travels when one cycle is completed. When radio waves are propagated through dielectric materials other than air, the effect is to slow down the wave or reduce the velocity of propagation. It follows that in coaxial cables using other than air dielectric, a wave travels slower; thus, a single cycle distance of travel would be less and a wavelength will be shorter.

The velocity of propagation in early (first-generation) foam dielectric cables is about 81% of that in free space. For later generations this has been improved to 88% or so, and for solid dielectric cables it is about 66%. From this we can develop a half-wavelength in inches for any frequency, both in free space (air) and in various dielectric cables. Table 8-B shows such a development using first-generation foam-dielectric cable. We show the development for both TV Channels 2 and 13 to facilitate this discussion. We will apply this data using Channel 2 picture carrier and first-generation cable to establish that both reflections would be in phase.

Table 8-B Wavelength

		Half-wavelength (inches)		
TV Chan.	Video Carrier Freq.	Air	Foam	Solid
2	55.25 MHz	103.8	84.0	68.5
13	211.25 MHz	27.7	22.5	18.2

In the first cable section in Figure 8-8, the spacing between taps 1 and 2 is 420 ft. or 5,040 in. Dividing this by the half-wavelength for Channel 2 in first-generation foam dielectric cable (84 inches), we have 60 half-wavelengths. If the spacing in the second cable section is precisely the same (420 ft.), the same 60 half-wavelengths is valid. Quite obviously both signals are in phase. The addition is a voltage addition, so if both R/S ratios were 48 dB, the net ratio would be 6 dB poorer or 42 dB. Note that at the input to tap 3, the original signal level was +32 dBmV. The net reflection now is only 42 dB down from the desired signal at -10 dBmV. Since all cable losses and return losses remained the same, this lower R/S ratio is entirely due to the in-phase addition of the two reflections.

In Figure 8-9 we have shortened one cable section from 420 feet to 416 feet and 6 inches. This section now represents a total of 4,998 inches and when divided by 42 is 119 quarter-wavelengths. This slight difference in cable length would have no significant effect on the cable loss, which we will still take to be 4 dB. Since cable loss and return losses remain as before, the R/S ratios are still 48 dB. But now the two reflections are out of phase with each other, and in theory, would cancel completely, although in practice this may not be entirely achieved. The net R/S ratio would now be improved by 6 dB and would be 54 dB (see Figure 8-9). Again this change is entirely due to the phase relationship, a function of cable length only since nothing else changed.

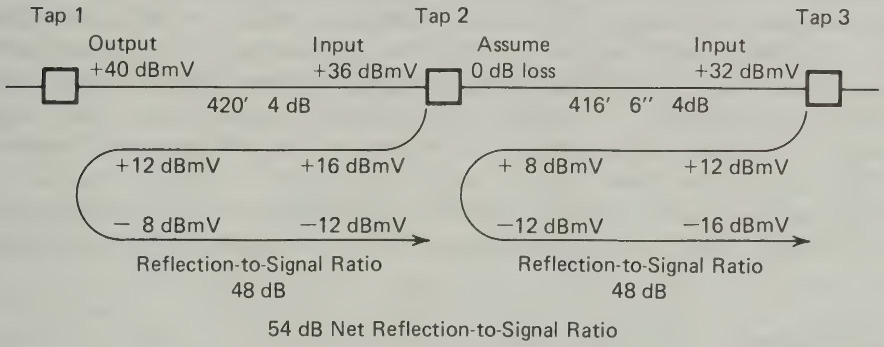

Tap 1
Tap 2
Tap 3
Output
+40 dBmV
Input
+36 dBmV
Assume
0 dB loss
Input
+32 dBmV
420′ 4 dB
416′ 6″ 4dB
+12 dBmV
+16 dBmV
+ 8 dBmV
+12 dBmV
− 8 dBmV
−12 dBmV
−12 dBmV
−16 dBmV
Reflection-to-Signal Ratio
48 dB
Reflection-to-Signal Ratio
48 dB
54 dB Net Reflection-to-Signal Ratio

Figure 8-9 Two Taps

If we reduce the spacing in the second cable section of Figure 8-8 by 126 inches, the total becomes 4,872 inches, which is 58 half-wavelengths at Channel 2. The difference between 240 feet (60 half-wavelengths) and 226 feet (58 half-wavelengths) is 2 half-wavelengths; thus, the reflections will again be in phase and additive, and the net R/S ratio would be degraded to 42 dB as before.

If we did this same analysis at Channel 13 frequency, we would find the same effect except the dimension need only change by 11.25 inches, a quarter-wavelength at that frequency. As we vary the spacing of one cable section we would find an out-of-phase length, an in-phase length, etc.

Eventually the spacing would change enough to significantly alter the delay time such that we would be addressing two separate reflections, and addition and cancellation would be somewhat academic.

The point of all this is the amount of variation in spacing that is involved. We cannot develop any rule that says identical 200 foot spacings must be avoided during system layout because it would be valid only if the probability of these spacings being precisely 200 feet in length is very high. We have seen that a variation of only 42 inches (3.5 feet) at Channel 2, and much less than that (less than a foot) at Channel 13, could actually reduce the amplitude of the reflection. It is a question of periodicity, that is, how often a particular spacing between irregularities is repeated in the system, but even relatively small variations present potential relief.

In laying out any system we must work with pole line maps or other data that do not present a degree of accuracy that would allow us to design around the problem of reflections. It is reasonable to expect that some percentage of apparently offensive spacings will actually be out of phase and cancelling. It must also be kept in mind that reflections that accumulate or build up will only be obnoxious to a small percentage of viewers at the end of the system; the reflections do not propagate back up the system. The radial cable route design, which splits cable to feed several side lead routings, will provide some degree of isolation from high-count tap cascades, and if it is necessary, we can "shed" or off load clusters of taps to further limit the potential problem.

Urban CATV System

Let us examine the "in-town" or urban application for a moment. Here we might expect the tap density to be higher and the spacing between taps shorter. We also might anticipate a high degree of periodicity, since poles, and consequently taps mounted at poles, would be spaced about the same distance apart. This distance is influenced by property lot lines, and lot sizes tend to be identical in many communities.

In Figure 8-7 we examined a spacing of 70 ft. The transmission time through foam-dielectric cable (first-generation) is about 1.24 nanoseconds per foot, then in a 70 foot section, the original signal is delayed 70 x 1.24 or 86.8 nanoseconds. The reflected signal would be delayed three times that amount or 260.4 nanoseconds. The difference in time delays is 173.6 nanoseconds or 0.1736 microseconds.

If 52.5 microseconds is the time required for a single line, then 0.1736 nanoseconds delay is only 0.33 percent of a horizontal line on a picture tube. On a 25 inch picture tube this is a displacement of approximately 0.1 inch and would not be perceptible. The delay incurred is so slight that even if increased in amplitude by in-phase additions, the reflection would not be sufficiently displaced to be visible.

The urban situation is further relieved by the basic design philosophy which limits all taps to "feeder" cable legs and the physical length of the "feeder" cables themselves.

We will discuss this in greater depth later in the text. There is ample evidence from hundreds of operating trunk/feeder type systems that reflections simply will not be a problem with tap cascades on the order of 40 units or so.

Rural CATV System

In rural applications we might expect longer physical spacings between taps. Then the reflections will be delayed significantly and might become more offensive. Fortunately, the tap loading under rural conditions is light (few taps required per mile) and property spacings will tend to be more random.

Mathematical studies and field tests on long tap cascades (not included here for brevity) indicate that rural tap cascades on the order of 100 units or more should be quite tolerable. Where the application requires higher quantities in cascade, prudent engineering practice suggests that the cascade be reduced by off loading or "shedding" some of the clustered tap load onto short sections of paralleling cable.

Local Area Data Networks

The nature of some networks might introduce both short spacings between taps and a high degree of periodicity also. Prudent engineering might disperse the taps on separate radial cable feeds or isolate taps in some other manner by system configuration. The evidence cited in the previous paragraph suggests that tap cascades on the order of 50 or more units should be quite tolerable, but some technical review of the question might be prudent.

As a point of information, it is possible to fabricate taps with higher return loss characteristics, but the cost of such units might increase. The fact that this action has not been taken reinforces the conclusion that reflections from a multiplicity of taps are not a problem in conventional or typical CATV systems today. The earlier types of taps, called "pressure taps," presented a gross mismatch in systems, and reflections were a much more serious problem in those days. The directional coupler type taps in general usage today are vastly superior to those earlier units.

Coaxial Cable Reflections

Although modern coaxial cables present excellent structural return loss characteristics, the nature of seamless aluminum outer conductor cables, and the unavoidable handling during fabrication and placement in the field, can introduce reflection problems. When semi-rigid cable of this type must be formed to enter housings, or bent around corners on poles, care must be taken to avoid kinking the cable, since each such kink represents a mismatch and initiates a reflection.

The possibility of smaller irregularities becoming magnified by the periodicity of their location along a section of cable is a problem. In cable placement in aerial construction, for example, an expansion loop is formed in the cable at each pole.

Since pole spacings may be repetitive in length, then the minor reflections introduced could fall in phase with each other and the composite reflection could become a problem.

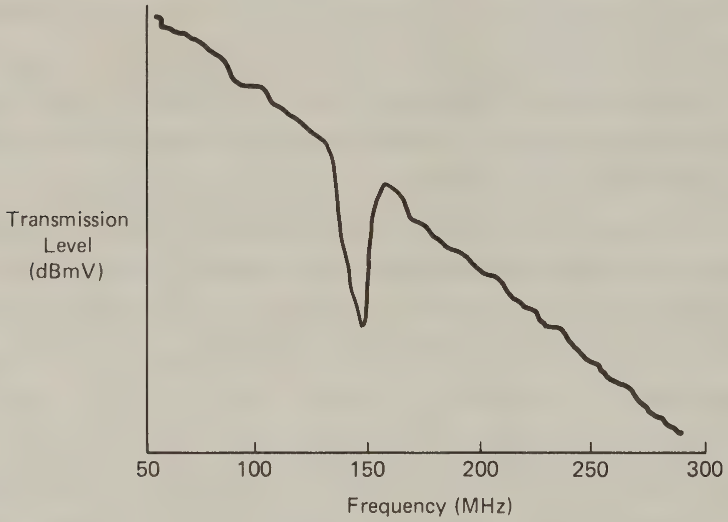


Figure 8-10 Frequency Response Distortion

Even in the manufacturing process, cable is somewhat vulnerable. During fabrication, the cable may be passed over several reels or capstans. If some mechanical irregularity develops on the surface of such units, the irregularity, however insignificant it might appear, will be precisely spaced along a piece of cable. The result can be increased transmission loss to only a very narrow portion of the transmission spectrum, much as a fabricated trap or narrow-band filter might introduce. In extreme cases, the section of cable may be unusable for one or several channels and would have to be replaced. This type of irregularity is sometimes called a "suck-out" (shown in Figure 8-10) because of the excess loss introduced to the affected channels only.

Summary

Understanding the generation and accumulation of reflections helps to understand cable and equipment specifications, particularly return loss. We can see how these figures impact on the end-of-system transmission quality.

We can see that the probability of precise spacing necessary for reflections to become offensive is small. We can understand the possible necessity for redistributing tap loads in some cases. We can see that if tap return loss figures were improved by manufacturers, the problem could be reduced.

Chapter 9

Automatic System Control

As is the case with any metallic conductors, variations in temperature affect the transmission loss of coaxial cables. When the cable is warmer it introduces more loss, and when it is colder it has less loss. In CATV systems we are involved with miles and miles of cable, and these changes due to temperature variation present a problem if remedial or corrective action is not taken.

Although we associate Automatic Gain Control (AGC) and other automatic correction techniques with thermal changes, some corrective methods are beneficially protective against signal level changes from other causes such as, for example, equipment aging, improper adjustment of equipment by service personnel, fluctuations in power source voltage, etc.

Temperature versus Cable Loss

Coaxial cable loss will vary on the order of one tenth of a percent for each one degree (Fahrenheit) of temperature change. A cable system involving 1,000 dB of total cable loss could be affected by as much as 100 dB change in loss across a temperature swing of 100 degrees F. Many sections of the United States might range from 0 degrees F to +100 degrees F on an annual basis.

And using one half inch coaxial cable, 1,000 dB total loss would be a system only 16 or 17 miles long. Such lengths would not be uncommon. Quite obviously we cannot ignore variations of this magnitude (100 dB) and expect to maintain compliant end-of-system transmission performance.

In Table 9-A we show the transmission loss through 5,000 feet of one half inch cable at 0 degrees F, +68 degrees F, and +90 degrees F. To demonstrate the change of loss at different transmission frequencies we show the losses for Channel 2 (55 MHz), Channel 13 (211 MHz), and Channel W (295 MHz). This is only 5,000 feet of cable, so the problems in a system of many miles of cable are quite obvious.

Table 9-A Cable/Temp. Loss (5 kft 1/2" cable)

Temperature	Chan. 2 (55 MHz)	Chan. 13 (211 MHz)	Chan. W (295 MHz)
+90 degrees F	26.4 dB	56.7 dB	66.9 dB
+68 degrees F	27.0 dB	55.5 dB	65.5 dB
0 degrees F	25.2 dB	51.8 dB	61.0 dB

Figure 9-1 shows four amplifiers interconnected by 1/2 inch coaxial cable. The transmission levels and losses are all taken to be at 300 MHz, and we assume that the system design called for +8 dBmV input and +40 dBmV output for all amplifiers. In Figure 9-1 all amplifiers shown are manually controlled, which means that once the gain has been manually adjusted, the units have no automatic readjustment capability at all. All system designs assume cable loss at 68 degrees F since this is considered to be the average cable temperature in the United States.

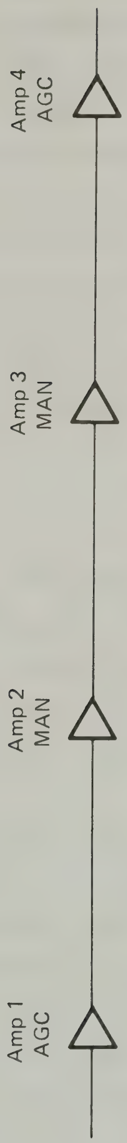
Figure 9-1 shows not only the changes in cable loss due to temperature variations, but the cumulative effects on amplifier input and output levels. At 68 degrees F we see that all inputs and outputs are maintained at the values the system designer selected. At +90 degrees F, however, we find that Amplifier 4 input level is +5.9 dBmV, rather than the design objective of +8.0 dBmV. At 0 degrees F, the output level of Amplifier 3 is +44.4 dBmV, while the design objective was +40 dBmV. Obviously, noise and X-Mod at the end of any significant cascade of amplifiers is going to be completely unacceptable.

Automatic Temperature Compensation

For many years we have been controlling home heating and cooling devices with thermostats, and certainly we can adapt this technology to sensing changes in temperature and initiating corresponding changes in devices such as amplifiers.

Applied in cable plant, this technique might be called passive thermal control. A thermal sensor, such as a thermistor perhaps, is introduced to control RF attenuation, which is automatically increased or decreased to reflect ambient temperature changes. In the early evolution of CATV equipment, this type of control was often provided in a small equipment housing that was spliced into the coaxial cable where the system designer or operating experience indicated. Today, similar devices are generally inserted as interstage components within an amplifier itself.

The technique might also be called "brute force," and is somewhat inadequate for long cascades or extended systems.


Amp 1
AGC
Amp 2
MAN
Amp 3
MAN
Amp 4
AGC

Temp. (°F)	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put
+90°	+40.0	32.7	+ 7.3	+39.3	32.7	+ 6.6	+38.6	32.7	+ 5.9
+68°	+40.0	32.0	+ 8.0	+40.0	32.0	+ 8.0	+40.0	32.0	+ 8.0
0°	+40.0	29.8	+10.2	+42.2	29.8	+12.4	+44.4	29.8	+14.6

Figure 9-1 Temperature versus Signal Levels

For example, the sensor location might actually be in a shady location while the majority of the cable was subject to direct sunlight. The ambient temperature of the two environments might vary considerably, and the compensation provided may not truly reflect the temperature excursions that the cable itself is subject to.

Another problem arises in underground cable installations. If the sensor is mounted above grade, it may not accurately track the cable temperature at all. Some manufacturers offered the sensor on the end of a six foot length of cable so that it might be buried at cable depth, but the RF attenuation that was controlled could be located in a housing above ground.

The most serious deficiency of this technique is that it provides no correction whatever in response to the actual signal level variations themselves. If, for any of a half-dozen reasons, the signal levels change without any change in temperature, the passive thermal control offers no relief. This method is still used in conjunction with more sophisticated devices as well as in very small systems by itself but one might anticipate somewhat higher levels of subscriber complaints, related higher maintenance costs, and the system is really not adequately equipped for subsequent extensions of any great length.

Automatic (closed-loop) Regulation

A much more positive control of system transmission levels can be achieved by tapping off and measuring the amplitude of RF pilot carriers, or regular television signals designated for control purposes. RF attenuation can then be introduced or removed from the amplifier RF transmission path in direct proportion to the amplitude measured on the control signals. Variations on this technique are also possible. For example, using the "closed-loop" technology, but sensing two separate control signals at different points within the spectrum, it is possible to provide some "slope" correction automatically but the basic principle is the same.

If the control equipment provides only "flat" transmission level control, it is called automatic gain control (AGC). In this case, if the control signal is sensed to be 1 dB low in amplitude, 1 dB of attenuation would be automatically removed and all signals present would be raised by 1 dB. If the control equipment provides some "sloped" transmission level control two signals would be sensed and the RF transmission loss removed would not be the same across the entire band of interest. This is called Automatic Slope Control (ASC) and may or may not be incorporated into every AGC equipment depending on individual manufacturer designs.

General Discussion

Generally, AGC and ASC is provided interstage in amplifiers where it has no significant impact on the amplifier C/N ratio. The RF sampling is accomplished through a directional coupler at the high-level amplifier output. The effect of removing RF attenuation is apparently increased amplifier gain.

Units are sometimes referred to as having reserve gain to overcome low input signal levels. The amplifier gain module is adjusted for some extra gain, but the actual compensating adjustment is usually the automatic insertion or removal of RF attenuation.

Automatic control equipments are generally specified to have a range of corrective ability, say, 4 dB correction capability, and this may be stated as; "for plus or minus 4 dB input level changes, the output level change will not exceed plus or minus 0.3 dB."

Automatic control, or self-regulation, is essential in systems of any practical length. It is quite important that we completely understand how it is implemented if we are to effectively incorporate it into systems.

Understanding Automatic Gain Control

As stated earlier, most AGC and ASC is accomplished by sampling the high-level RF output of the amplifier and measuring the amplitude of the control signals or designated TV carriers. A DC control voltage is produced that reflects the amplitude of the monitored RF signal and this is used to control an interstage RF attenuator. Perhaps a greatly simplified example of AGC will clarify this.

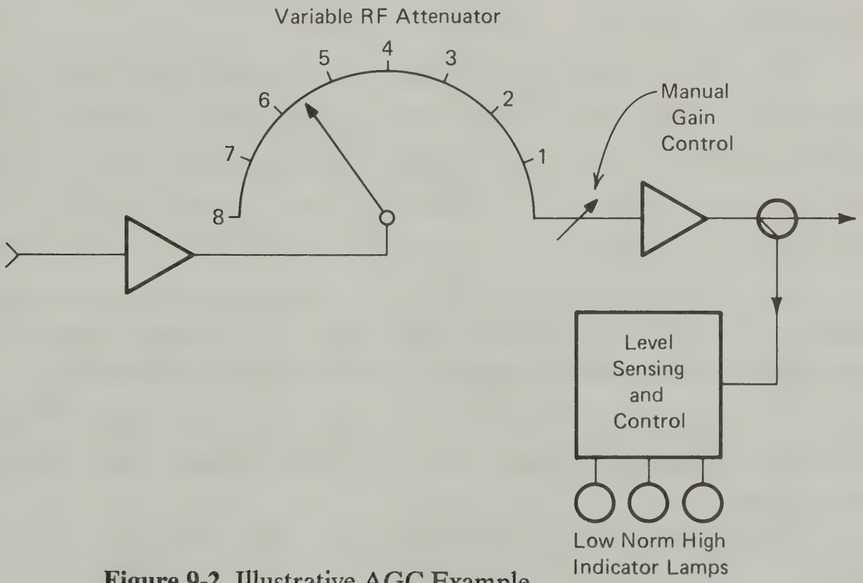


Figure 9-2 Illustrative AGC Example

Figure 9-2 shows a manually adjusted RF attenuator, connected in series with a manual amplifier gain control, with both of these installed between the input and output stages of an amplifier. At the amplifier output (high RF level) we have a directional coupler sampling RF energy, which is fed into a sensing and control unit.

In this example we will detect and indicate with the three indicator lamps shown, low, normal, or high level RF amplifier output. We can then respond to the indicated RF output level by manually switching in more or less RF attenuation using the variable attenuator.

Initial Test Setup

We will feed a +8 dBmV input signal level, as measured on the designated control carrier, into the amplifier. If we set the variable attenuator at its mid-range point, with 4 dB of attenuation inserted, we could adjust the manual amplifier control for any desired level of amplifier output. If +40 dBmV is the desired normal amplifier output, we will set the output to this level using the manual gain control only.

Some RF output energy will be diverted, through the directional coupler, to the sensing and control unit, and we could calibrate the unit such that the Normal indicator lamp was lit but both the Low and High lamps were extinguished when the amplifier output was +40 dBmV. Of course the signal levels given here (+8 dBmV and +40 dBmV) are arbitrary and were selected for demonstration purposes only. Other signal levels could be designated and used.

Example 1

If we now reduced the RF input to the amplifier by 2 dB (to + 6 dBmV) the output of the amplifier would also be reduced by 2 dB and the sampled RF fed into the sensing unit would be 2 dB lower in amplitude. The sensing unit would recognize this lower level and would extinguish the Normal indicator and light the Low level indicator lamp. We could respond to the indication of low RF output level by manually adjusting the variable RF attenuator until the amplifier output level came back up to +40 dBmV. This would require switching out 2 dB of loss.

The sensing unit would recognize the restored normal output level of +40 dBmV, would turn off the Low indicator, and light up the Normal lamp. We would stop varying the attenuator when the lamp showed normal output level again.

Now let us take our amplifier RF input signal and bring it back up 2 dB to the normal +8 dBmV level. The amplifier output would also increase 2 dB. The sensing unit would measure the higher level, turn off the Normal lamp, and light up the High level indicator.

We could respond to the indication of high output level by adjusting the RF attenuator, this time increasing attenuation until the output level returned to the normal +40 dBmV output as indicated by the High level lamp being extinguished and the Normal indicator being turned on. Now we are back where we started, with normal amplifier input (+8 dBmV), 4 dB of variable RF attenuation switched in, and normal amplifier output (+40 dBmV) present as indicated by the Normal indicator lamp being lit.

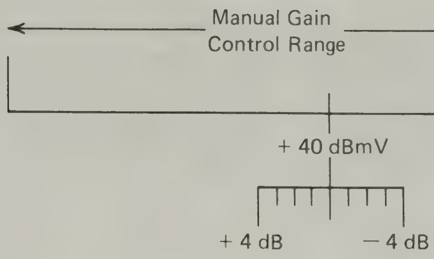


Figure 9-3 AGC "Window" (examples 1, 3, and 4)

Note that the corrective range at our disposal was limited to the variable RF attenuator range of 0 to 8 dB. Let us refer to this as the automatic control "window." During our initial setup of the amplifier, we positioned the "window" such that it gave us a plus or minus 4 dB correction, as referenced to the designed +40 dBmV (normal) output level. We did this by setting the attenuator at mid-range and then using the manual gain control to establish the +40 dBmV output level. But the corrective range available ("window") was still limited to 8 dB.

If the variations in amplifier input level we artificially introduced had actually been caused by temperature changes in a long coaxial cable run feeding this amplifier, the process would have been precisely the same. We can then see that input level changes of plus or minus 4 dB could have been compensated quite easily by varying the RF attenuator. In Figure 9-3 we show the relationship of the "window" to the manual gain control range and the normal +40 dBmV output level.

Example 2

We left the demonstration unit with +8 dBmV of input, 4 dB of variable attenuator loss, +40 dBmV of output, and the Normal indicator lamp lit. Let us switch out all the variable attenuation, that is, switch the RF attenuator to zero loss. Now we can still use the manual gain control to reestablish the +40 dBmV output level and the Normal indicator lamp will still light to show this. Now we have +8 dBmV of input, zero RF attenuation inserted, +40 dBmV of output, and the Normal output indicator lit.

Figure 9-4 shows the "window" position relative to the +40 dBmV output level under these conditions. Now, just as we did earlier, let us reduce the input level to the amplifier by 2 dB. Since nothing else was changed, the amplifier output level would drop accordingly (2 dB), the sensing unit would recognize low output level, turn off the Normal lamp, and light the Low level indicator.

Our earlier response to an indication of low output level required us to raise the output level by removing some of the RF attenuation, but when we set up the demonstration this time, we had already set the RF attenuator at 0 dB.

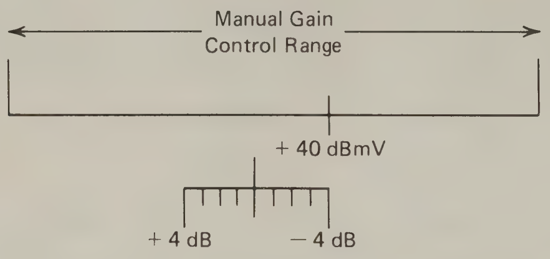


Figure 9-4 AGC "Window" (example 2)

We cannot correct the RF output level now because we have no correction range of attenuator available, that is, we cannot switch out attenuation because the unit is not inserting any attenuation.

Let us make a gross change in the amplifier input level by increasing it 6 dB, from a normal +8 dBmV level to +14 dBmV. The output would also increase 6 dB, the sensing unit would measure high output, turn off the Low indicator lamp, and light up the High indicator lamp.

We could respond by switching in RF attenuation until the output level was again +40 dBmV which the sensing unit would recognize as normal, and it would so indicate by switching off the High lamp and switching on the Normal lamp. Now we have +14 dBmV of input, 6 dB of RF attenuation switched in, +40 dBmV of output, and the Normal indicator lamp is lit.

In this example, note that although the attenuator range was always 8 dB (the "window"), but we positioned it with one edge of the corrective range located at the normal +40 dBmV output, and due to this incorrect positioning, we could not use the manual gain control to correct for any input levels below +40 dBmV. We could correct for higher input levels, up to +48 dBmV actually, but we could not accommodate lower input levels.

Example 3

Restore the +8 dBmV of input, switch in 4 dB of RF attenuation, and using the manual gain control, restore the +40 dBmV of output. Obviously, the sensing unit will see a normal output and will light the Normal indicator lamp. In Figure 9-3 we showed the position of the "window" as it now is. Now we will increase the RF input to the amplifier by 5 dB. The output level will follow and the sensing unit will measure and indicate high RF output. We respond by adding all the available RF attenuation from the preset 4 dB to 8 dB, but this cannot restore the output level to normal (+40 dBmV) since we reached the end of the range of the "window."

The RF output would be attenuated 4 dB, to a +41 dBmV output level, but the High output indicator would not be extinguished and we have no additional correction we can make. However, note that if this amplifier had been followed by another AGC unit in a system, the first amplifier (our model) would correct for 4 dB, and the second amplifier would have been able to correct for the remaining small error of only 1 dB.

Example 4

There is another operating example that would be instructive to examine. Restore all conditions to normal; that is, +8 dBmV amplifier input, 4 dB RF attenuation inserted, +40 dBmV output as adjusted with the manual gain control, and the sensing unit indicating a normal output and illuminating the Normal lamp. The "window" position would now be as shown previously in Figure 9-3.

Now we will simulate a total loss of control carrier by removing the RF input to the amplifier entirely. The amplifier output will not have any control carrier present either, but the sensing unit is not sufficiently sophisticated to recognize that the control carrier is completely absent; it simply assumes that the carrier level has been reduced in amplitude, consequently it illuminates the Low signal level indicator.

We would respond to the Low indicating lamp by reducing the RF attenuation, but even if we switch out all the attenuation, the output signal cannot be restored since it is completely absent. The sensing unit simply continues to indicate low signal level, but no adjustment of RF attenuation can restore the output signals. In this condition, the amplifier is producing maximum gain. If all other RF signals normally passing through the amplifier had not been removed, that is, if only the control carrier was removed, the X-Mod contributed by the amplifier in this condition would be 8 dB higher than it would have been at normal operating gain since the output level would be 4 dB higher than normal.

AGC in System Design

We artificially introduced the changes in the amplifier input signal levels to demonstrate the process of output level detection and correction. Quite obviously, if our model amplifier had been one unit in a cascade of working amplifiers, the changes in input signal levels might have been actually caused by temperature changes in the interconnecting cable itself, by incorrect adjustment of a preceding amplifier by service personnel, or by equipment aging, etc.

Of course an actual AGC amplifier has no indicating lights, and no manual response in attenuator adjustment is necessary. The sensing unit itself produces DC control voltage changes that directly switch the RF attenuator value, but the process is essentially as we have described it here. Note that the unit was sensing output level only and could not directly recognize or correct changes in input level.

In our examples we used +8 dBmV input and +40 dBmV output as operating signal levels established by the system designer. These were arbitrary values used for example purposes, of course, but how does a system designer actually determine these levels and what process is followed in positioning AGC or ASC (Automatic Slope Control) amplifiers within an actual system?

In the previous chapters we have discussed in some detail the design processes of determining end-of-system performance requirements and reconciling these with system length, amplifier cascade, amplifier characteristics, and then logically establishing the necessary operating input and output levels that are required. All of these items are factors in the transmission engineering phase of system development which assures that the end product, the actual system constructed, will be fully compliant with the required performance specifications. If the reader is uncertain of the transmission engineering process, a review of the previous chapters is indicated.

The problem now is to pursue applications engineering processes such that the original system design, which we assume to be technically sound and fully responsive, cannot be compromised in the normal environment that the plant must be exposed to. We are not really addressing transmission objectives now, since we have already done this satisfactorily. What we are obliged to do now is to protect the transmission integrity of the original design, and in a sense, this phase of design work might be called defensive or protective rather than initiative.

The system designer, well aware of the temperature variations that the cable plant will be exposed to across seasonal changes in that particular area, and from the transmission design results, knowing the interconnecting cable lengths involved, must calculate the variations in signal levels that the system will normally encounter. A judgement must be made as to the variations in signal level that the designer is prepared to accept before applying corrective compensation in the form of automatic system controls. On the basis of calculated variations, the designer must examine the technical and economic impact of AGC or ASC correction at every amplifier location, at every second location, and so on. For example, in underground cable plant where the temperature variations will be much less extreme, the designer might opt for correction at every fifth amplifier location.

In general, the tendency has been to use as few AGC amplifiers as possible since manually controlled units without any automatic corrective capability at all are less sophisticated, and consequently less expensive. But with integrated circuit equipments, the cost differential between AGC amplifiers and simpler manual units is no longer quite as significant as it used to be, and there are several good arguments for using more AGC or ASC units rather than the absolute minimum that may be theoretically acceptable. We will discuss this in depth in the next chapter.

We must remember that the designer assumed the normal cable temperature to be 68 degrees F, and on that basis, established input and output operating signal levels as well as determining how far apart automatic correction units would be spaced. Under these conditions, in our examples, the amplifier input level was taken to be +8 dBmV.

In actuality, it may be necessary to install and adjust an automatic control amplifier when the ambient temperature is not 68 degrees F. Under such conditions, and assuming the previous amplifier in the cascade did have the correct +40 dBmV output level, the input level to the subsequent unit in the cascade would be higher (at lower temperatures) and lower (at higher temperatures) than +8 dBmV, and this would be a perfectly normal condition. If we do not recognize the signal level variation this creates and compensate for it when we initially adjust the control "window" position of the AGC or ASC unit, we may seriously affect the overall system automatic control capability.

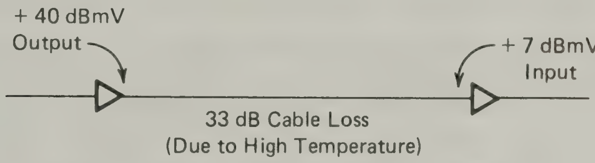


Figure 9-5 High Temperature Cable Loss

Example 5

In Figure 9-5 we show an amplifier presenting a stable +40 dBmV signal input into a connecting coaxial cable section which, at a normal 68 degrees F, would have introduced 32 dB of transmission loss. This would produce the normal +8 dBmV input to the next amplifier in the cascade that we have used throughout all our examples. But in Figure 9-5 we show the cable as having 33 dB of transmission loss, not the 32 dB the system designer anticipated. We will assume that this 1 dB of additional loss is due to a higher ambient temperature and thus should be considered a normal situation.

Now the input level to the second unit in Figure 9-5 is an explainable +7 dBmV rather than the design level of +8 dBmV. The second amplifier output would reflect this as a +39 dBmV output level if it were operating with no automatic control capability at all. Note that this would be a perfectly normal operating condition.

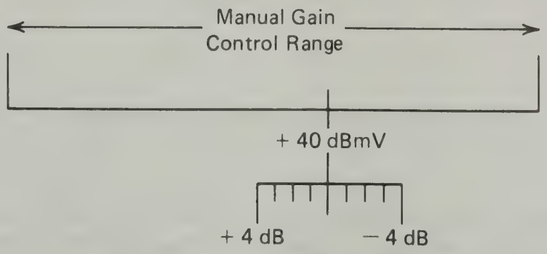


Figure 9-6 Low Level Input

If we did not recognize the lower input level to the amplifier as explainable, and simply proceeded with the normal AGC amplifier adjustment process as was used in Example 1 earlier in this chapter, the AGC "window" might be improperly positioned as shown in Figure 9-6. We would have set the variable RF attenuator to mid-point, that is, with 4 dB of loss inserted, and then adjusted the manual gain control to produce a +40 dBmV output level. At first glance, Figure 9-6 appears to be quite correct, but remember that the input signal level while this adjustment was made was actually +7 dBmV due to the high ambient temperature being experienced at the time.

Consider what happens when the temperature returns to normal, 68 degrees F. The cable loss would be reduced to the normal 32 dB, and the second amplifiers input would be increased from +7 dBmV to +8 dBmv. The AGC unit would sense this in a 1 dB higher output level and would automatically switch in 1 dB of compensating RF attenuation. This would leave the amplifier with a normal +8 dBmV input and a normal +40 dBmV output, but now the "window" would be positioned such that the amplifier could only correct for 5 dB lower input level and 3 dB higher input level, rather than the plus or minus 4 dB changes it was intended to accommodate. We can see this clearly in Figure 9-7.

The "window" position in Figure 9-7 is incorrect because our initial intention was to be able to recognize signal input levels that were either 4 dB higher or 4 dB lower than +8 dBmV and to adjust the amplifier output levels within this range of input variations to +40 dBmV. With the positioning shown in Figure 9-7, subsequent gross temperature excursions might demand amplifier corrections beyond the range of 3 dB, and as shown in the figure, the unit would be unable to respond adequately. The error in positioning of only 1 dB may seem insignificant, however, if many AGC amplifiers are replaced or readjusted over a long period (perhaps years of operation) in a long cascade of amplifiers and an error of this magnitude was introduced each time, the system self-regulation capability could become quite marginal.

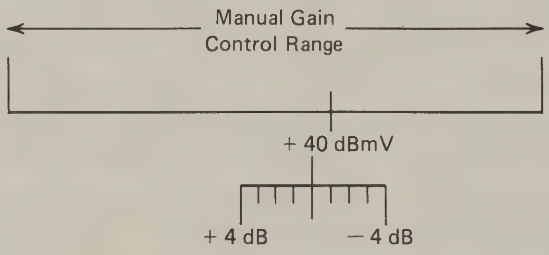


Figure 9-7 Incorrect "Window" Position

The system designer has introduced the AGC (or ASC) on a sound basis of predicted temperature excursions and known cable lengths. He or she expects each AGC unit can and will produce its specified correction capability.

If, through many improper equipment adjustments over an extended period of time, the AGC units do not present that corrective capability, the end-of-system performance may go out of specifications during temperature excursions that the designer actually had made adequate provision for.

In adjusting any automatically regulating amplifier at any time, the system technician should measure amplifier input levels and reconcile them with the current ambient temperature. If the variations in signal level can be correlated with temperature, then the AGC "window" should be positioned so that the unit is actually contributing some correction at that time. Then, when the temperature returns to normal, the amplifier will readjust itself and the full regulatory control range of the unit will be restored.

If the input signal variation does not correlate with temperature, then the variation should be considered to be abnormal and should be investigated further as a possible trouble condition in the cable system itself.

Recognizing and adjusting for abnormal signal levels due to normal temperature excursions is not limited to automatic control amplifiers alone. In adjusting manual amplifiers, the technician should recognize legitimately high or low input signal levels and set amplifier output levels accordingly. Perhaps the most misunderstood and most frequently abused work operation in operating CATV systems is the adjustment of manual and automatic amplifiers. The reader is encouraged to review this entire chapter if he or she is not completely comfortable with the process.

Summary

Different equipment manufacturers configure their equipment differently, of course, and the particular controls provided may vary widely. Most will bear little resemblance to our example with lamps and corrective adjustments, but all AGC and ASC amplifiers do present a fixed or limited range of self-correction, that we have called the "window," and all provide some flexibility in positioning this "window."

The reader should carefully follow the manufacturers recommendations for particular equipment, but perhaps now the reader will have a better understanding of the operations he is performing, and the implications of such operations as well.

Chapter 10

Applying Regulation in Systems

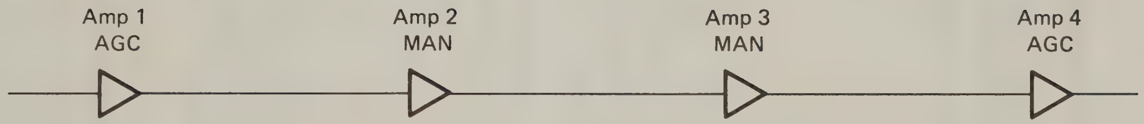
How much automatic regulation should be provided in a system is a difficult thing to determine. Although the general practice has been to use as few automatic control units as possible on the basis of reduced initial cost, as systems become more sophisticated, carrying many more channels and other services, the arguments for more frequent self-regulation in systems become more persuasive. Perhaps the best place tc start is to plot the impact of thermal change for several conditions of system construction and then analyze them.

We will arbitrarily restrict all presentations to 300 MHz and 1/2-inch foam-dielectric type coaxial cable but will examine the complications of different amplifier gain and spacing. And we will, of course, have to differentiate between aerial and underground plant.

Thermal Effects in Aerial Plant

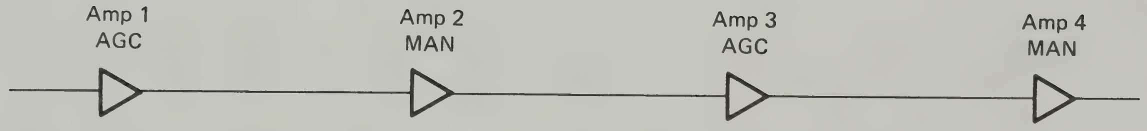
In Figure 10-1 we have plotted temperature changes and their effect on signal levels through a cascade of four amplifiers. We used 22 dB amplifier spacing in this example, and are utilizing AGC amplifiers at every third equipment location. For instructional purposes only, we have arbitrarily selected +10 dBmV input and +32 dBmV output levels.

Assuming the AGC units could accept +4 or -4 dB input level changes and still regulate for a +32 dBmV output, the input levels presented to amplifier 4 in Figure 10-1 are not within regulating limits. At zero degrees F, the input is +14.5 dBmV and the unit can regulate only a four dB variation from the design objective of +10 dBmV. Under these conditions, assuming the amplifier AGC does have it's full range of corrective capability, the output level from amplifier 4 will still be +32.5 dBmV, a half dB above the design objective.


Amp 1
AGC
Amp 2
MAN
Amp 3
MAN
Amp 4
AGC

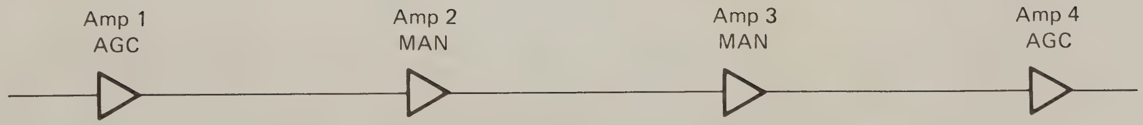
Temp. (°F)	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put
+90°	+32.0	22.5	+ 9.5	+31.5	22.5	+ 9.0	+31.0	22.5	+ 8.5
+68°	+32.0	22.0	+10.0	+32.0	22.0	+10.0	+32.0	22.0	+10.0
0°	+32.0	20.5	+11.5	+33.5	20.5	+13.0	+35.0	20.5	+14.5

Figure 10-1 Aerial Cable (AGC every third unit)


Amp 1
AGC
Amp 2
MAN
Amp 3
AGC
Amp 4
MAN

Temp. (°F)	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put
+90°	+32.0	22.5	+ 9.5	+31.5	22.5	+ 9.0	+32.0	22.5	+ 9.5
+68°	+32.0	22.0	+10.0	+32.0	22.0	+10.0	+32.0	22.0	+10.0
0°	+32.0	20.5	+11.5	+33.5	20.5	+13.0	+32.0	20.5	+11.5

Figure 10-2 Aerial Cable (AGC every second unit)


Amp 1
AGC
Amp 2
MAN
Amp 3
MAN
Amp 4
AGC

Temp. (°F)	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put
+90°	+40.0	32.7	+ 7.3	+39.3	32.7	+ 6.6	+38.6	32.7	+ 5.9
+68°	+40.0	32.0	+ 8.0	+40.0	32.0	+ 8.0	+40.0	32.0	+ 8.0
0°	+40.0	29.8	+10.2	+42.2	29.8	+12.4	+44.4	29.8	+14.6

Figure 10-3 Aerial Cable (32 dB spacing)

We must recognize that the C/N ratio of amplifier 4 at +90 degrees F has been degraded by 1.5 dB due to the reduced input signal level, and the X-Mod of amplifier 3 at zero degrees F will be 6 dB worse than the design objective since the output level of amplifier 3 at zero degrees F is 3 dB high. Keep in mind that the four-amplifier cascade shown might be duplicated many times over in an actual system, consequently the two examples of a poor C/N ratio and high X-Mod would apply to one third of the system amplifiers under the temperature extremes shown. Whether or not this is an acceptable level of AGC is somewhat questionable.

In Figure 10-2 we have increased the density of AGC to every other station; all other conditions remain unchanged. We find both previous conditions much improved. The worst-case C/N ratio we will experience now will be a 1 dB degrade at the input to amplifier 3 at +90 degrees F. Worst-case X-Mod is amplifier 2 at zero degrees F with a 3 dB degrade possible. This condition will surely be more acceptable than the previous example as the cascade of units is increased.

What about AGC at every station? We do not really need to plot these, of course. Regulation at every station should ensure that calculated end-of-system X-Mod will be realistically produced and maintained. Some C/N ratio degradation will accrue at every station with the worst-case being at +90 degrees F, but this should change end-of-system C/N ratio by only 0.5 dB. Obviously this is the most technically desirable configuration but economics must also be considered.

Let us do this same development series for amplifiers spaced 32 dB apart, using +8 dBmV input and +40 dBmV output levels. Figure 10-3 shows AGC at every third station. Worst-case C/N ratio is the high temperature input to amplifier 4, which is 2.1 dB poorer than design. X-Mod at zero degrees F at the output of amplifier 3 is degraded 8.8 dB. The most significant thing is that even if the AGC at amplifier 4 can accept a +4 to -4 input variation, at +14.6 input the AGC cannot fully correct the amplifier 4 output level. Even at amplifier 3, with +12.4 input and a design objective of +8.0 input, the AGC could not restore normal output levels. Quite obviously, at 32 dB spacing with AGC every third station, the system falls apart very rapidly even under predictable temperature excursions.

There is little point in plotting AGC at every other station, and it is unnecessary to plot for every station. We can see from amplifier 2 in Figure 10-3 that the worst-case C/N ratio, with AGC at every location, will be degraded only 0.6 dB, occurring at +90 degrees F. X-Mod should be exactly as the designer predicted in this case.

General Discussion

Since the cable loss change due to temperature change is a percentage of total cable loss, the variations in transmission losses and signal levels would be the same regardless of operating frequency. For example, Figure 10-1 was based on a 300 MHz upper transmission frequency. The cable had 1.31 dB loss per 100 feet at 68 degrees F, and 22 dB of cable would be 1,680 feet. At 400 MHz, that same cable would have a 1.53 dB loss per 100 feet at +68 degrees F. Then 22 dB of cable would be 1,438 feet.

But the change in loss is 1 percent per 10 degrees F temperature change in both cases. Since both cases assumed 22 dB spacing, the transmission level changes would be the same. Thus, the plots presented are equally applicable for any upper limit frequency (200 MHz, 300 MHz, 400 MHz. etc.) although the physical length (spacing) between amplifiers would be significantly different.

We can see that higher-gain amplifiers will increase the need for AGC since they would increase the cable span lengths. It is also quite apparent that if AGC stations are incorporated as infrequently as possible, based upon their full corrective capability being available, and if that full corrective capability is not actually achieved in practice, the end-of-system performance may be marginal even if the density of AGC were every alternate station. This points out the importance of correctly adjusting automatic control stations.

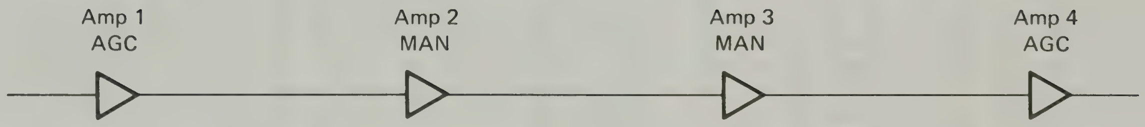
In effect, a system design places amplifiers so as to precisely overcome the transmission loss that a single length of interconnecting cable introduces. Automatic regulation units are placed, at a minimum, to correct the predictable transmission loss changes that the anticipated temperature variations will produce across some number of interconnecting cable lengths. We are free, of course, to place automatic regulation units more frequently than this if there were some compelling reason to do so.

Thermal Effects in Underground Plant

With cable placed underground, the impact of temperature changes is substantially reduced. Studies indicate that temperatures at a 30 inch depth will average +50 degrees F, and that even extreme temperature swings at that depth will not exceed +75 degrees F to +25 degrees F.

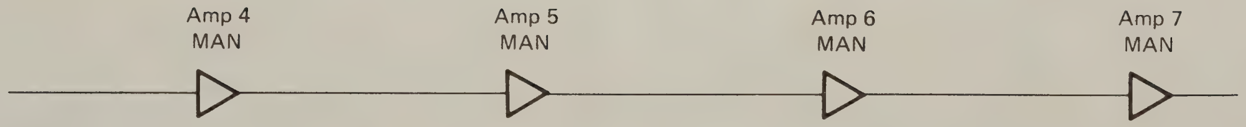
In Figure 10-4 we show an underground system four-amplifier cascade with AGC at every third location and 22 dB spacing. Worst-case C/N ratio is at amplifier 4 input at +75 degrees F producing a 1.8 dB C/N degradation. X-Mod is poorest at amplifier 3 output at +25 degrees F and would be degraded 2.4 dB. Amplifier 4 would have no difficulty in regulating output levels since input variations are well within the +4 to -4 correction range. One might conclude from reviewing Figure 10-4, that we could design the system with a lower density of AGC than every third station. If we consider only the corrective range of the AGC units, this is correct.

Figure 10-5 shows amplifier 4 from Figure 10-4 as the first station in a cascade of seven units, but without AGC. We can then follow the development until we reach input levels that are beyond the AGC corrective range. Consider the input level to amplifier 7 at +75 degrees F. It is +6.4 dBmV, 3.6 dB below the designed +10 dBmV input level. This particular amplifier has a C/N ratio 3.6 dB poorer at this temperature. Consider amplifier 5 input level. It is +7.6 dBmV or 2.4 dB below the designed +10 dBmV. This unit has a 2.4 dB poorer C/N ratio at +75 degrees F. Consider the output level of amplifier 6 at +25 degrees F. It is +35.0 dBmV, 3 dB above the design output level of +32 dBmV. This unit will produce 6 dB more X-Mod at +25 degrees F.


Amp 1
AGC
Amp 2
MAN
Amp 3
MAN
Amp 4
AGC

Temp. (°F)	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put
+75°	+32.0	22.6	+ 9.4	+31.4	22.6	+ 8.8	+30.8	22.6	+ 8.2
+50°	+32.0	22.0	+10.0	+32.0	22.0	+10.0	+32.0	22.0	+10.0
+25°	+32.0	21.4	+10.6	+32.6	21.4	+11.2	+32.2	21.4	+11.8

Figure 10-4 Underground Cable (22 dB spacing)


Amp 4
MAN
Amp 5
MAN
Amp 6
MAN
Amp 7
MAN

Temp. (°F)	In Put	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put	Out Put	Cable Loss	In Put
+75°	+ 8.2	+30.2	22.6	+ 7.6	+29.6	22.6	+ 7.0	+29.0	22.6	+ 6.4
+50°	+10.0	+32.0	22.0	+10.0	+32.0	22.0	+10.0	+32.0	22.0	+10.0
+25°	+11.8	+33.8	21.4	+12.4	+34.4	21.4	+13.0	+35.0	21.4	+13.6

Figure 10-5 Underground Cable (22 dB spacing)

At +75 degrees F, all amplifiers are producing a C/N ratio progressively poorer than the design objective. Even with AGC at every station, we could not eliminate a 0.6 dB degradation in C/N ratio at every amplifier at +75 degrees F. Note that the input to amplifier 2 in Figure 10-4, which immediately follows an AGC station, is 0.6 dB below the designed input level. Thus, at high temperatures, the C/N ratio for the cascade of seven units will degrade 0.6 dB at a minimum.

The purpose of this development was to reinforce earlier instruction. The question is not simply one of periodically reestablishing operating RF signal levels. We must recognize the nature of noise and intermod accumulation in cascades of amplifiers. We may elect to utilize fewer automatic control units in systems for other reasons, economy may be one, but we should appreciate the impact on the system of such a decision.

In the interest of brevity we will not present the underground cable plot for 32 dB spacing. Serious students are encouraged to develop such a chart simply to reinforce their understanding of the factors involved. The methodology is quite straightforward.

Economics of Automatic Regulation

In considering the costs of automatic control (AGC and ASC) we have to recognize the wide range of costs which a large number of suppliers presents. In the earlier days of CATV development, the cost differential between manually controlled and automatically controlled units was substantial. And in those days, we were not loading systems as severely either, since we were carrying fewer TV channels. The practice of AGC at every third station, while not universally adopted, was generally employed in aerial plant in view of these facts.

With the equipments available today, the cost differential is much smaller. In one particular product line, both AGC and ASC capability can be added to a station for under $100. If we assume a conservative average requirement of 3.5 amplifiers per route mile of cable, we would add only $350 per mile cost if we installed AGC at every station. But this assumes we had the option of a system that employed no AGC at all. Our earlier discussion showed this to be unrealistic, so we would have had to have perhaps one AGC station in every mile of plant anyway.

Then the upgrade to 100 percent AGC from, say, 33 percent, with AGC at every third station, is about $250 per mile using this particular equipment. Upgrading from 33 percent, the minimum AGC acceptable by arbitrary assumption, to 50 percent AGC, with every alternate station an AGC unit, the cost penalty is $175 per mile. With overall plant costs on the order of perhaps $9,000 a mile and up, this may be acceptable.

High-Level Self-Regulation

If we place AGC at every station, we can consider the system as having a very high level of self-regulation.

Ignoring for the moment the economic penalties of such a choice, are there any compensating advantages? Our plots of the thermal effect on signal levels throughout a system do indicate that AGC at some level below every station can be technically acceptable. Even assuming temperature extremes, which will surely be experienced infrequently, the degradation of end-of-system performance could be acceptable. But it is simplistic to consider temperature variations as the only problem.

There are several other possible causes of signal level variation, most of which do not lend themselves to analysis or prediction nearly as well as temperature changes. For example, equipment aging or partial loss of amplifier gain defy any logical approach at prediction. Minor changes in cable loss due to moisture ingress would be equally probable and random. But perhaps the most widespread cause will be improper system adjustments by personnel, both during initial alignment and over extended periods of operation.

The basic philosophy of automatic regulation is derived from thermal requirements and is most readily associated with temperature changes; however, a broader point of view seems to be emerging. As we add services and signals to systems, their tolerance to level variation diminishes. At the same time, the revenues produced by the many new services increase, placing new emphasis on maintaining high transmission quality.

Perhaps the emphasis should be on maximum system "invulnerability" or, as the miltary might state it, "system hardness." We might address the question from the point of view of protecting the quality of transmission against any and all signal level variations, regardless of the root cause. And since we cannot reasonably predict which portion of a system may be subject to the most variation, one might argue that we must protect the entire system equally well.

The prolific use of automatic control (self-regulation) cannot protect against equipment failure, of course, nor can it totally eliminate improper adjustments by personnel, but it can reduce to some degree the impact of both on the system. Given a partial loss of gain in a single amplifier, for example, the AGC at the next amplifier location would immediately correct the levels, thus restricting the lower signal level and its effect to only a single amplifier.

Given even a total failure of AGC at any amplifier, the next station in line (AGC, of course) would compensate fully and subscriber service quality would be largely unaffected. Consider a total failure of AGC installed at every third station. We would have six cable sections and five intermediate amplifiers with no corrective self-regulation at all. Our earlier examination of thermal effects alone shows that this will almost invariably produce substandard end-of-system performance.

Given AGC at every station, one obvious advantage is logistical. All amplifiers are now identical and spare equipment varieties are reduced. All amplifier operating levels, at least within an identifiable element of the system such as the trunk or super-trunk, would be the same for all equipments, or very nearly so, most of the time. This may permit a lower level of sophistication in long-term system maintenance or in service restoration operations.

Reducing the complexity of system operation could have a significant impact on long-term system operating costs, which might well offset the nominal initial cost penalty for more self-regulating units. We cannot entirely eliminate the need for sophistication both in servicing personnel and in test equipments and procedures, but we may be able to somewhat reduce the requirements and perhaps do more of this level of work on a scheduled, non-emergency basis. A system with a high level of self-regulation will be an essential element in any such program.

Potential AGC Problems

There are unique problems associated with AGC even at low levels of utilization. When we state that the system is regulated, we must recognize that this regulation is contingent upon properly adjusted and fully operative AGC units. However, consider the total loss of the controlling carrier or carriers. In Example 4 of the preceding chapter we showed that the amplifier would "open up" fully, that is, remove all RF attenuation, in such a situation. The AGC sensing unit is not very sophisticated. It does not sense the total loss of regulating carrier at all, just the reduced level.

Thus, the AGC unit "fails hard" rather than "fails soft." What we mean is that the unit does not respond by restoring neutral RF attenuation. If the amplifier were previously operating near normal temperature with, say, 4 dB of RF attenuation inserted, it now will increase the output level by 4 dB since it would remove all RF attenuation. We know that increasing output level by this amount (4 dB) will immediately increase intermod (X-Mod or CTB) by twice this amount, or 8 dB.

Since all AGC units in the system, whatever the density, would receive no regulating carrier, they would all react exactly the same way, "fail hard," and all would introduce 8 dB additional intermod. Even at a density of AGC at every third station, a gross increase of this magnitude, affecting one-third of the system amplifiers, would undoubtedly put the system out of specification as to X-Mod.

If the AGC density was 50 percent and each amplifier went 8 dB higher in X-Mod, the end-of-system X-Mod would go up 4 dB or so. If the AGC density was 100 percent, the system X-Mod would be 8 dB poorer. Either of these conditions would surely be out of specification as far as end-of-system performance is concerned. This possibility is perhaps somewhat remote, given the reliability of modern head end equipment, but it certainly points out the need for an automatic standby carrier in the event the primary control carrier actually fails.

We would prefer that AGC "failed soft," that is, that on a loss of control carrier it would automatically self-adjust to a mid-range of RF attenuation. But the additional sophistication required of each AGC unit would obviously increase their cost. Since there is only one head end and many AGC units in a system, it is much more logical to absorb the cost of redundant control carrier generators at the head end.

However remote the possibility of control carrier loss may appear to be, we might still consider alternatives to reduce the impact of such an untimely event on end-of-system performance. There are strong arguments in favor of 100 percent AGC, and the

CATV industry is beginning to adopt this philosophy. If AGC is installed at every station, the requirement for a wide range of control (we have been using +4 to -4 dB input variations in our discussions) is somewhat reduced. If, by redesign, the AGC range were restricted somewhat to +3 to -3 dB, or even +2 to -2 dB perhaps, then when AGC units "fail hard," the resultant change in output level would be less pronounced, and consequently the increase in X-Mod produced in each unit would also be lower.

Another practical alternative might be to simply position the AGC "window" to correct for only 2 or 3 dB lower input level variations rather than 4 dB since we have to correct for only one cable span. Now if we lost the control carrier, the unit could open up only 2 or 3 dB from normal attenuation, limiting the additional X-Mod introduced to 4 or 6 dB rather than the previous 8 dB.

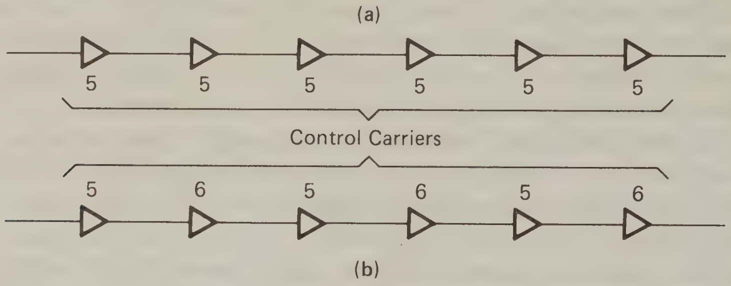


Figure 10-6 Redundant AGC

There may be an even better alternative, however. In Figure 10-6a we show six amplifiers, all with AGC and all responding to Channel 5 as the control carrier. Any total loss of Channel 5 would have serious impact on system performance. In Figure 10-6b we show the same six-amplifier cascade, but now every other station is responding to Channel 6 as a control carrier. Since both Channel 5 and 6 are normally present as "in-service" channels on the system, we have incurred no additional head end equipment cost. And since AGC units are equally available for Channel 5 or 6, and at the same cost, we have no additional system equipment cost either.

Now a total loss of either control carrier (Channel 5 or 6) will affect only every other AGC amplifier, consequently the impact on system performance would be reduced. Note we did not surrender any of the advantages of 100 percent AGC, but only configured a redundant type of system self-regulation.

One might argue that with two control carriers, the probability of losing one is higher. Perhaps so, but the impact of such a loss is greatly reduced. With a single control carrier we had almost no hope of continuing satisfactory service through most of the cable system if it were lost.

With the redundant AGC approach, service might be sustained through much of the system, since every second amplifier would tend to correct immediately for the loss of one control carrier.

Throughout our discussion of AGC we have, for simplicity of presentation, referred to only one control carrier. Most modern systems today use two carriers and provide Automatic Slope Control (ASC) as well. The reader should understand that this was implied in all our examples too. In a redundant configuration we might, for example, have been using Channel 2 and 12 at every other station, and Channel 3 and 13 at the alternate stations.

High-Level Self-Regulation Applications

By considering these alternatives, we have hopefully developed a better understanding of AGC and ASC as they are implemented in actual practice. There are specific applications commonly encountered in CATV systems that respond particularly well to 100 percent AGC installation, and it might be appropriate to point these out.

In our earlier discussion of super-trunk, we recognized that the super-trunk plant would be followed by conventional distribution cable plant also. For this reason, it was designed to produce low intermod distortion. For this same reason, a super-trunk cannot tolerate large variations in noise or intermod from any root cause, particularly since the tandem or cascaded distribution plant may be subject to precisely those same variations if they are thermally originated. A super-trunk is a most logical requirement for high-level self-regulation.

In conventional urban CATV systems, usually no AGC is provided in feeder plant amplifiers. Since there are many more of these than there are trunk amplifiers, the cost reduction overall is quite significant. But if AGC is provided at every second trunk amplifier only (50 percent density) and an intermediate manual control trunk amplifier serves as a distribution point for two or three feeder amplifiers, subscribers near the end of the feeder plant can be receiving signals which pass through three or four serially connected, unregulated amplifiers. The quality of service for a substantial number of customers can be affected. In such cases, 100 percent AGC in the trunk plant alone can have very beneficial effects.

Our earlier discussion clearly showed that higher-gain amplifier systems, with longer physical spacings, were particularly susceptible to thermal variations. But the marginal economics of thinly populated rural areas almost forces us to use higher-gain equipment. And in small, marginal operations such as most rural systems, experienced personnel are difficult to find and even more difficult to afford. Quite clearly, rural systems are a prime candidate for 100 percent AGC.

Local Area Data Networks (LANs) are generally restricted in cable length and usually require only a nominal amplifier cascade. Most such installations also maximize underground cabling, or locate most of the cables inside buildings or structures where temperature excursions are somewhat limited.

Despite the sophisticated nature of the intelligence transmitted, such as high-speed digital data for example, many LAN installations will require no AGC at all and most will not require a high-density of self-regulation. Nevertheless, the logistical advantages of identical equipments and the high level of system invulnerability that 100 percent regulation can provide, suggest that such designs merit serious consideration.

Summary

With an understanding of self-regulation and its effect on systems, both economically and technically, we are better qualified to recognize those situations or applications that might be cost-effectively addressed by using more (or less) AGC. As stated at the beginning of this chapter, the decision as to how much self-regulation to provide is a difficult one to resolve, but perhaps we are now somewhat better equipped to address it logically.

Chapter 11

Frequency Response and Equalization

In addressing any transmission system, we must be concerned with the frequency response across the bandwidth that the system presents for use. If the response for different sections of this bandwidth is not the same, the fidelity with which the system output reproduces the input information, will suffer.

When we consider the transmission bandwidths provided in CATV systems, typically from 50 to 300, 400, or even 500 MHz, we can anticipate that such systems will present some frequency response problems. With a large number of discrete signals distributed across the spectrum provided, variations in system response means variations in the amplitude of the signals themselves.

We can logically divide system response distortion into two categories, both forms being characteristic of different system components or devices. We will refer to these as "distributed distortion" and "cable distortion."

Peak-to-Valley Response

We define frequency response for both systems and individual units of equipment in terms of peak-to-valley response. This denotes the most extreme deviations in the pass band of the device or system. For example, in Figure 11-1 we have plotted the attenuation through a device across 50 to 300 MHz. If the device had no response distortion, the dotted line would be the measured data, though we actually plotted the measured data shown by the solid line.

This hypothetical unit was specified to introduce a 0.5 dB loss across the band 50 to 300 MHz. But the specifications also called out a maximum response ripple (peak-to-valley) of 0.4 dB. Note in Figure 11-1 that we measured a 0.2 dB insertion loss at 100 MHz and a 0.6 dB insertion loss at 250 MHz. These were the two most extreme variations. The difference between 0.2 and 0.6 is 0.4 dB; thus, this unit does meet specification.

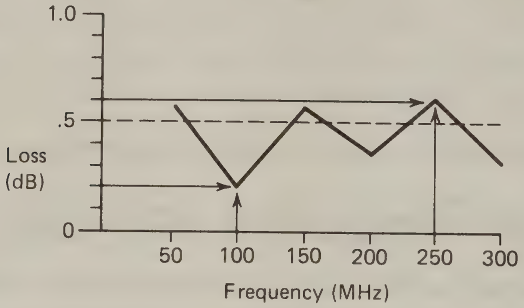


Figure 11-1 Peak-to-valley Response A

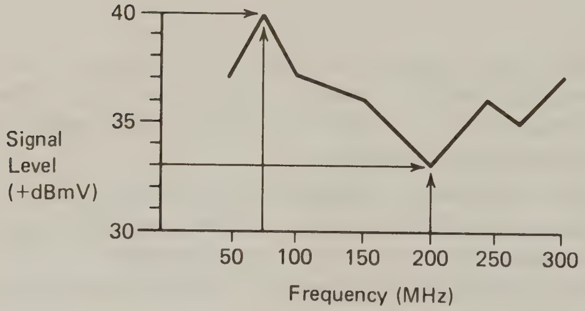


Figure 11-2 Peak-to-valley Response B

In Figure 11-2 we see the response of a cascade of amplifiers. In this illustration the highest measured signal level was +40 dBmV at 75 MHz, and the lowest measured signal level was +33 dBmV at 200 MHz. This system would be said to have a peak-to-valley response of 7 dB (40 - 33 = 7).

When we connect many components together, as we must if we are to construct a usable system, we can anticipate that distortion of the overall frequency response will occur. As mentioned earlier, some small, incremental corrective adjustments can be made in each system amplifier. If necessary, it is also possible to periodically install "mop-up" equalizers that can provide some correction for sections of the pass band.

Equipment Response Distortion

The many discrete devices employed in a CATV system (taps, amplifiers, splitters, etc.) will each contribute some distortion to the overall system frequency response.

Since these devices are mass produced, similar units will introduce similar distortion, sometimes referred to as "signature." A particular value tap, for example, might have a roll off of response at one end of its transmission bandpass. Several of these same units connected in series would exhibit a more pronounced roll off of response at that same end of the band.

Amplifiers themselves are produced in quantity, and not only does each individual unit have a characteristic response "ripple," but a cascade of identical units would exaggerate the condition. Amplifiers sometimes have some internal adjustment in order to correct response, and although the range of such adjustment may be limited, it may often rectify some of the response distortion that preceding passive units may have introduced.

Generally, we can ignore the minor frequency response "ripple" introduced by the amplifiers and passive devices. The distortion is random in nature and relatively minor, and the distortion from one device may even correct for that from a preceding unit, thus it is quite difficult to predict the distributed distortion that may accumulate, except in very long cascades of similar passive devices.

Of course, the subscribers' television receivers are necessarily designed with a respectable dynamic range and most will accept nominal variations in signal levels and still produce good quality pictures. But the "tilt," a form of frequency distortion introduced by the long lengths of coaxial cable, is too pronounced to be ignored.

Cable Response Distortion

The differential in transmission loss through even 2,000 feet of half-inch coaxial cable, between a lowest transmission frequency of 50 MHz and a highest of 300 MHz, is on the order of 16 dB or so. The impact of this on amplifier performance cannot be ignored, and it is the noise and intermodulation distortion introduced by the amplifiers that is the most significant factor in system transmission quality.

We must compensate or correct for the inherent frequency/loss characteristics of coaxial cable to optimize amplifier performance. We do this by equalization.

Equalization

Equalization is a technique to reestablish a desired relationship that has been disturbed between transported signals by the different transmission losses of the coaxial cable that the signals have been passed through. We cannot alter the characteristics of the cable, and the effect of passing the signals through the cable is different changes in the levels of the transported signals. We can and do manipulate the signal levels so as to help offset the effect of cable "tilt." The end result, for transmission purposes, is the same as if we actually had been able to manufacture cable with "flat" loss, that is, cable that had the same transmission loss for all frequencies passed through it.

To demonstrate this, in Figure 11-3 we show the attenuation characteristics of a 2,000 foot cable across 50 to 300 MHz. Below the cable graph we show the effect on a band of signals presented to the cable at equal levels. Note the "flat" input signals where the amplitude of any carriers between 50 and 300 MHz are all the same. The output of the cable section is shown in the center of the bottom drawing. Here the amplitude of a 50 MHz signal would be much higher than that of a 300 MHz signal and intermediate signals would vary proportionally.

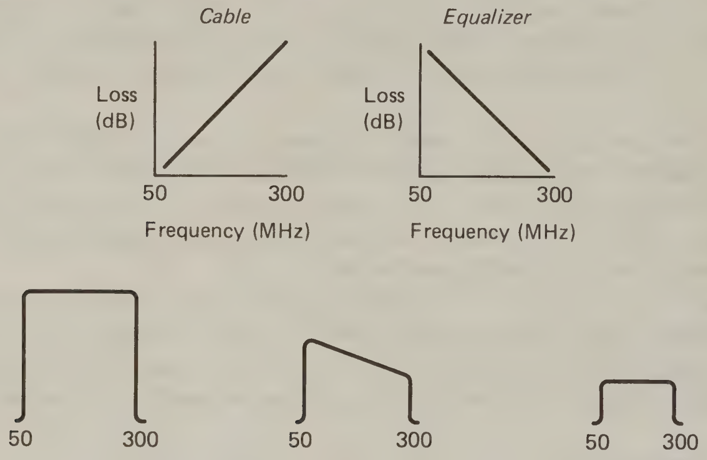


Figure 11-3 Equalization

Figure 11-3 also shows the attenuation characteristics of an equalizer, and the bottom right hand drawing shows the output of an equalizer connected to the end of the cable section. Note that the amplitude of any signals passing through the combination of cable and equalizer would, for all practical purposes, be the same.

Note that the input signals to the cable were "flat" and the output signals from the cable/equalizer combination are also "flat." As we progress through the cable plant, this is precisely what we attempt to do. The signal levels are distorted by the sections of cable and we try, through the use of equalizers, to restore them to equal amplitude. Each cable section then will ideally compensate for its own "tilt."

We also do this for gain and loss within each cable section. Every amplifier is intended to precisely offset the loss of the cable section immediately preceding it, and every equalizer is intended to precisely offset the tilt of the preceding cable section. Thus, a cable section consisting of the coaxial cable and an amplifier, is operated at unity gain with no difference in signal levels between the inputs and outputs of the section.

Perhaps an example will help explain this more completely.

Characteristics of Coaxial Cable

Coaxial cable does not exhibit the same transmission loss for all frequencies passed through it. Actually, the loss increases as the square root of frequency. The result is, for example, a higher signal loss at Channel 13 (211 MHz) than at Channel 2 (55 MHz). We will call this characteristic "tilt," and it is equally true of the coaxial cables we employ for subscriber service drops.

This characteristic of coaxial cable is constant and the effect is linear and predictable. Thus, we are able to calculate the "tilt" that a specific length of cable will introduce and design an equalizer that will compensate for that "tilt," or very nearly so. Note that in actual systems we will be inserting devices such as splitters, directional couplers, and subscriber taps into the cable section. All of these devices will affect the transmission loss and thus the physical cable length between amplifiers.

These devices introduce almost the same transmission loss to all frequencies within their pass band. They do not introduce substantial amounts of "tilt," and are generally referred to as "flat" loss devices. When we calculate equalizer values that may be required in a cable section, we usually ignore all "flat" losses and consider only the length of the interconnecting cable. For example, if two amplifiers were spaced 22 dB of loss apart, but the cable section included 4 dB of loss from inserted passive devices, we need an equalizer to correct for 18 dB of cable, not 22 dB of transmission loss.

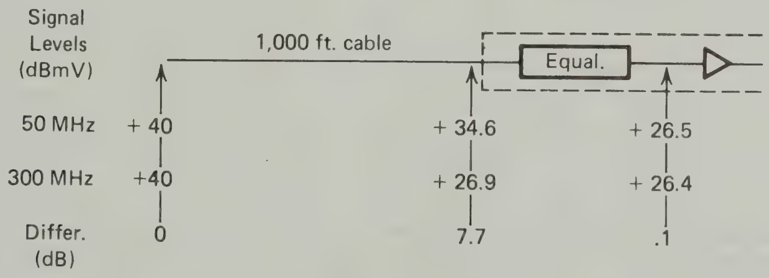


Figure 11-4 Equalization

In Figure 11-4 we show a 1,000 foot section of cable and indicate the signal levels at both 50 and 300 MHz at points along the cable. For this example we used equal input signal levels of +40 dBmV. At the input to the amplifier housing, the differential in level between 50 and 300 MHz is 7.7 dB. We would select an equalizer that introduced this same differential in loss, except it would have the higher loss at 50 MHz and the lower loss at 300 MHz, and this would present both signals to the amplifier module input at the same level, or very nearly so. Note the differential in levels at the module input is shown to be only one tenth of a dB in Figure 11-4.

Most manufacturers specify equalizers simply as being equivalent to a specific length of cable. For example, a 13 dB equalizer, for a 300 MHz system, would be the corrective unit for a length of cable having 13 dB of loss at 300 MHz. This would be approximately 1,000 feet of half-inch cable. Such a length of cable would have 5.45 dB of loss at 54 MHz and 13 dB of loss at 300 MHz. The equalizer would actually have insertion loss of perhaps 0.5 dB at 300 MHz and 8.1 dB at 54 MHz.

If we utilized such an equalizer in Figure 11-4, we would produce input levels to the amplifier gain module very nearly equal in amplitude, and thus achieve our objective. It is important to understand just how the manufacturer designates the equalizer characteristics. In this example, the designation 13 dB made no direct reference to the unit's insertion loss at any particular frequency, but was referenced to the loss and thus the length of the preceding cable that the unit would equalize properly. The signal levels used in our example are purely arbitrary, of course.

Irregularities in Cable

The frequency/loss characteristics of cable just discussed are predictable and can be corrected by proper equalization. However, the cable may also evidence some "ripple" in its frequency response, generally less significant and random in nature. In the manufacturing process as well as in the handling and placement during construction, the cable may be slightly mechanically damaged or distorted, affecting the frequency/loss characteristics.

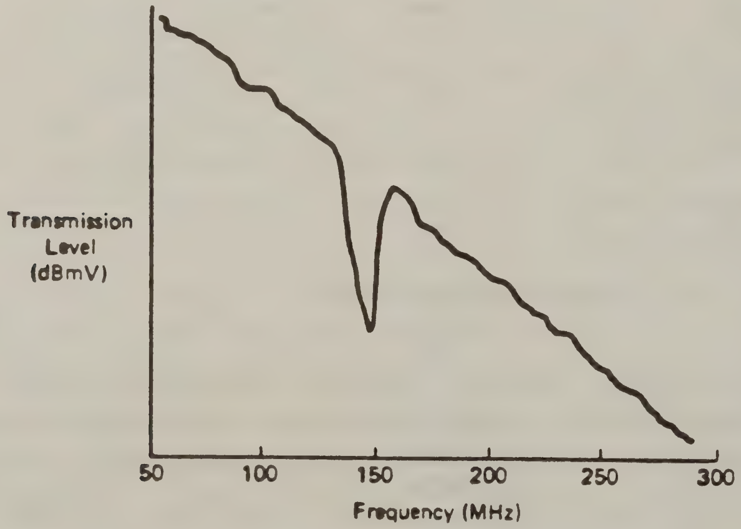


Figure 11-5 Frequency Response Distortion

Not only can a single bad kink or sharp bend introduce distortion, minor imperfections can have a dramatic effect if they are periodic and spaced identical distances apart. The result can be dramatically increased transmission loss in only a portion of the transmission spectrum, much as a trap or narrow-band pass filter might have.

In extreme cases, the section of cable may be unusable for one or several channels and must be replaced. This is sometimes referred to as a "suck out" because of the excess loss of signal to the affected channels only. Figure 11-5 shows such an irregularity. Gross irregularities of this type are abnormal and would usually be detected by cable tests or during the initial system alignment process. The system designer cannot predict such abnormalities, and consequently cannot protect against them. The designer can, however, predict and accommodate the entirely normal frequency/loss characteristic referred to as "tilt," and he is obliged to do so during the design process by selecting proper equalization. But end-of-system performance quality and amplifier operation are not the only considerations of frequency response.

Subscriber Service Requirements

The end result of any CATV design and construction effort is service to subscribers. Ideally, we would deliver to each and every subscriber, television signals at a sufficiently high level for the subscriber's receiver to produce good, clean pictures. In addition, and again ideally, all delivered signals would be at the same level, since the TV receiver would then function equally well with any of the delivered signals.

In actual practice, the frequency/loss characteristics of coaxial cable make this impractical to accomplish. The variable lengths of cable, including the service drops themselves, required to serve so many separate locations simply cannot be accommodated with precision. Fortunately, the end device served (the television receiver) can tolerate some variations without degrading the quality of the pictures displayed.

In designs, we compromise by limiting the variations we will accept in the level of the signals presented to the receiver. The Federal Communications Commission (FCC), having jurisdiction over cable television technical standards, requires all signals to be within a 12 dB range at the subscriber's television receiver. This may be called the "window" for variation. Most cable system designers specify a more stringent 9 dB "window." During the design and layout phase of work, the designer cannot know what service drop lengths will be required so it is customary to specify the signal level "window" at each subscriber tap output port instead.

The usual method is to determine what the average drop length will be. Then a decision must be made as to how much signal level is required at the subscriber's house end of the service drop. It is then fairly simple to specify both signal level and "window" at the tap output port, the point of service drop input.

For example, suppose we wish to utilize RG-59U service drop cable that has a loss of 2 dB per 100 feet at 50 MHz and 4.42 dB per 100 feet at 300 MHz. We survey the area and establish 125 feet as the length of the majority of service drops. Then our drop losses will be 2.5 dB at 50 MHz and 5.5 dB at 300 MHz.

If we decide we will accept +3 dBmV at the house end of every service drop (an arbitrary figure as used here), we must provide at least +8.8 dBmV at the drop input or tap output port at 300 MHz. Most designs would round this out to +10 dBmV to accommodate variables and provide some prudent margin.

But the service drop had 3 dB of "tilt" in it, with 2.5 dB of loss at 50 MHz and 5.5 dB at 300 MHz. Then the acceptable "window" at the house end of the drop (we will use 9 dB for this example) must be 3 dB tighter, or only 6 dB, at the tap output port. We then have a specification for every tap output port of +10 dBmV or more at 300 MHz, with a "window" no greater than 6 dB. The system designer can take this into account in selecting all tap values during system layout.

Tilted System Operation

Earlier we discussed "tilting" the amplifier output levels to improve amplifier performance. If we had no subscriber service drops to consider, we could simply adjust signal levels at both ends of each cable length as we had discussed. But how much pre-tilt we introduce into the system will be a consideration of the tap output "window" specification we just developed.

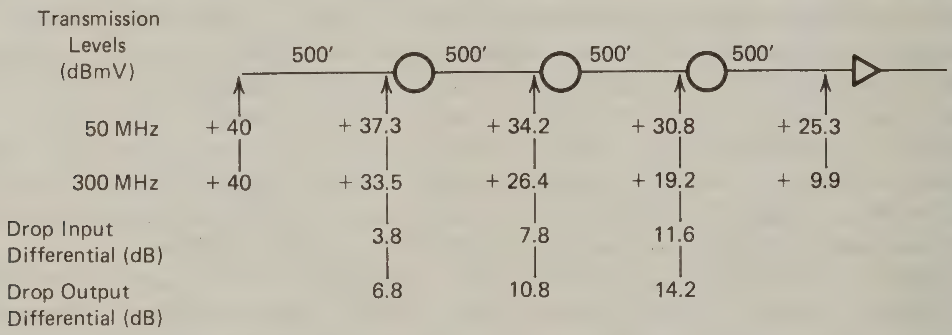


Figure 11-6 Frequency Response "Window"

In Figure 11-6 we show a 2,000 foot cable section with all input signals at an identical amplitude of +40 dBmV. We show three subscriber taps at 500 foot intervals along the cable, with each tap feeding a 125 foot service drop of RG-59U cable. The transmission levels are shown for input to each tap at both 50 and 300 MHz. We have also shown the differential in signal level between 50 and 300 MHz at both the service drop input and the service drop output, which is at the house end of the drop.

Note that the first tap is well within our house end "window" specification of 9 dB, but the other two taps are out of specification (10.8 and 14.2 dB differential). They are both out of specification at the tap output port also, of course.

Specification was a 6 dB "window" at the tap port, and the two levels in Figure 11-6 are +7.8 dBmV and +11.6 dBmV, respectively. The input to the amplifier presents no real problem. We could simply select a compensating equalizer, but this will not rectify the violations of "window" specifications for the service drops.

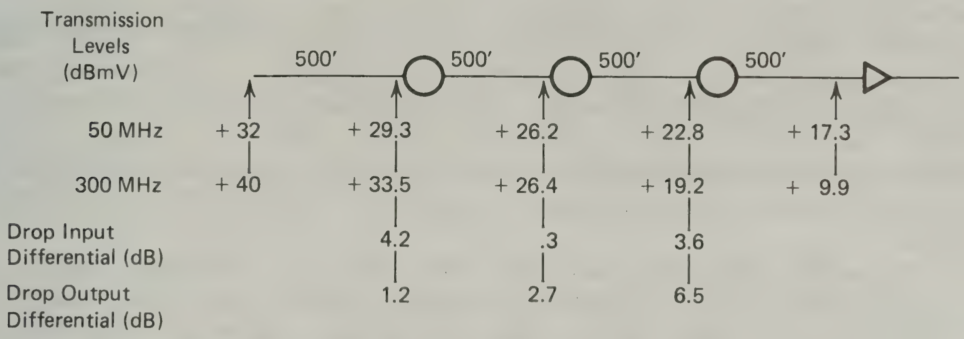


Figure 11-7 Frequency Response "Window"

In Figure 11-7 we have precisely the same conditions and the same service drop losses and specifications apply, but we have "tilted" the input signals to the cable section by 8 dB. The 50 MHz carrier is now at +32 dBmV but the 300 MHz carrier remains at +40 dBmV as before. Of course all other signals are graduated in level accordingly. Note that all three service drops are now in full compliance with the "window" specifications, both at the tap output end and at the house end.

In this example we used a +40 dBmV output and a long cable section (2,000 ft.) to demonstrate the application of "tilted" operation. These conditions might be quite different if many more taps were involved, for instance in an urban feeder cable, or if higher-loss cable were used, or lower-gain amplifiers were involved. The determination of how much "tilt" the system requires must consider all these factors, and in many cases only 5 dB of "tilt" might be applied. But the principle and the development is precisely the same, only the figures would change. This is true of systems with an upper transmission frequency limit of 450 or 500 MHz as well.

In some very long, tapped cable sections, it may be advantageous to insert an in-line equalizer to tighten up on the tap output port "window," but this is not a mandatory requirement and often can be avoided by increasing the amount of system "tilt" provided in system amplifier outputs. Later in the text when we discuss system design techniques, we will discuss this possibility in greater depth and present examples.

Tap Selection During System Design

The actual layout of a tapped section of plant can be accomplished by a series of manual calculations or may be computer assisted, thereby speeding up the process.

There is nothing particularly difficult about the process but it does require a number of repetitive calculations.

If we examine Figure 11-7, interested readers can follow the process. We used a 1.31 dB loss at 300 MHz (per 100 feet of cable) for the main cable run. Then each 500 foot cable span introduces 6.55 dB of loss at 300 MHz and 2.7 dB of loss at 50 MHz. The input to the cable section was +40 dBmV at 300 MHz and +32 dBmV at 50 MHz.

Then the input levels to the first tap are calculated to be +40 - 6.55 = +33.45 dBmV at 300 MHz, and +32 - 2.7 = +29.3 dBmV at 50 MHz. To provide a +10 dBmV input to the service drop, we will utilize a 23 dB tap, and if we had two drops at this location it would be a two-port tap. Referring back to Table 3-B in Chapter 3, a two-port 23 dB tap will introduce 0.4 dB of loss into the main cable. Then we are leaving this location on the main cable with levels of +33.0 dBmV at 300 MHz and +28.9 dBmV at 50 MHz.

At the service drop input, the signal levels will be 23 dB lower than the tap input port level since we used a 23 dB tap value. This will be +10.5 dBmV at 300 MHz and +6.3 dBmV at 50 MHz. This is a differential of 10.5 - 6.3 or 4.2 dB as shown in the figure. The service drop cable introduces a 2.5 dB loss at 50 MHz and a 5.5 dB loss at 300 MHz. The signal levels delivered at the house end of the drop then, are +5.0 dBmV at 300 MHz and +3.8 dBmV at 50 MHz. This is a differential of 5.0 - 3.8 or 1.2 dB, as shown in the figure. The process continues in just this fashion and is identical for Figure 11-6 also. As you can see, it is not sophisticated at all, just arithmetic. Later in the text we will develop several designs demonstrating this process.

Summary

Frequency/loss characteristics of wideband systems do require consideration in system design and layout, but the work operations required are neither difficult or complex. The values used in our examples were arbitrarily selected for illustrative purposes and should not be considered recommendations or requirements, but the methodology demonstrated is directly applicable in any application, regardless of the transmission bandwidth of the system involved.

Chapter 12

Elements of System Design

There are several techniques of designing systems that can be effectively employed for different demographic requirements. If we first acquire some familiarity with the elements of system design, since basic considerations apply to some degree in all applications, we may facilitate our understanding of these subsequent discussions.

Tapping Efficiency

Regardless of what particular design is employed, the system must accommodate subscriber service drops so a thorough understanding of system service tapping is essential. In Chapter 3 we defined the subscriber tap and presented a table of typical tap parameters (see Table 3-2), but these units were specifically identified as presenting a usable bandwidth to only 300 MHz.

Many modern systems today present bandwidth capability to 450, 500 or even 550 MHz. In Table 12-A we present tap parameters for a series of one manufacturer's units that present 550 MHz of bandwidth. Note that the Table gives two values for each parameter, one at 50 MHz and one at 550 MHz. As we learned in Chapter 3 when designing wide bandwidth systems, say more than 300 MHz of bandwidth, we are obliged to perform two series of calculations, one representing transmission loss accumulation at 50 MHz, and a second series for transmission losses at 550 MHz, or the highest transmission frequency that is to be used in the system under development.

In order to become thoroughly familiar with both 300 MHz designs and broader bandwidth applications, we will examine some applications of both. In Figure 12-1 we show a cable section with a +32 dBmV input and three tap locations. We will assume all taps are two-port units (capable of serving two individual drops), and we will select tap values from Table 3-2 in Chapter 3 for a 300 MHz example.

Table 12-A Subscriber Tap Parameters (losses in dB)

Tap Value (dB)	50 MHz		550 MHz	
	Tap Loss	Insert Loss	Tap Loss	Insert Loss
2 Way Taps				
38	38.2	.30	39.5	.80
35	35.2	.30	36.2	.70
32	32.0	.30	34.0	.60
29	29.4	.30	31.0	.70
26	26.0	.40	27.0	.70
23	23.3	.30	24.0	.80
20	19.5	.40	20.4	.80
17	17.1	.30	17.5	1.00
14	14.6	.70	16.0	1.30
12	11.7	1.10	12.0	2.30
10	10.1	1.50	11.0	2.00
7	6.4	3.40	7.0	4.30
4T (term.)	3.4	----	3.7	----
4 Way Taps				
38	38.2	.30	39.0	.60
35	35.5	.30	36.1	.70
32	32.0	.30	32.1	.70
29	29.6	.30	30.2	.40
26	26.2	.30	26.5	.75
23	23.4	.30	22.8	1.30
20	20.1	.60	20.2	1.10
17	17.2	.90	16.8	1.60
15	15.5	1.00	16.1	1.90
14	13.8	1.50	14.2	2.00
12	12.1	2.30	12.8	3.00
10	10.0	3.40	11.4	3.85
7T (term.)	6.4	----	7.0	----
8 Way Taps				
38	39.3	.30	39.5	.60
35	35.9	.40	36.5	.70
32	33.1	.30	33.2	.70
29	29.4	.30	30.0	.70
26	26.7	.40	27.0	.85

23	24.8	.50	24.2	1.40
20	21.5	.70	21.6	1.50
17	18.8	1.50	18.4	2.00
14	16.1	2.70	16.5	3.10
10T (ter.)	10.2	----	11.6	----

The specifications require a +10 dBmV minimum input to every service drop and we will use 1.0 dB per 100 feet for cable loss.

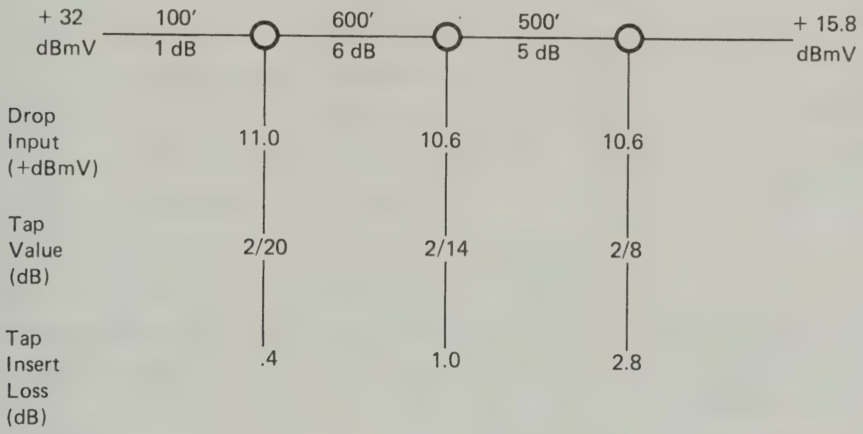


Figure 12-1 Tap Insertion Loss (low RF levels)

Given a +32 dBmV cable section input level at the first tap location, after passing through 1.0 dB of cable loss, the signal input level to the tap will be +31 dBmV. In order to provide the required +10 dBmV input to the service drop, we will use a two-port 20 dB tap. The input to the drop will be 20 dB below the tap input level of +31 dBmV, and thus will be +11 dBmV as shown in the figure. Note that the tap insertion loss is 0.4 dB, so the signal level leaving this tap to proceed on down the cable would be +30.6 dBmV.

After passing through 6.0 dB of cable, the input to the second tap will be +24.6 dBmV. A two-port 14 dB tap would produce a service drop input level of +10.6 dBmV which is within specified requirements. A 14 dB tap inserts 1.0 dB of loss, so the signal level leaving the second tap is now +23.6 dBmV. There is 5 dB of cable loss in the cable between the second and third taps, so the input to tap three will be +18.6 dBmV. A two-port 8 dB tap provides a +10.6 dBmV input to the service drop, and with 2.8 dB insertion loss in such a unit, the output from the tap into the cable is +15.8 dBmV.

Although there is nothing technically imprecise in this development, and it clearly demonstrates the selection of tap values in a 300 MHz system, it would be easier if we had a more methodical process, particularly if we had a great deal of system design work to do. We could tabulate the information, helping to avoid omissions or errors and certainly making analysis easier. In the following tabulation, the output level shown for one line item actually represents the input level to the next line item.

Device or Cable	Insert Loss/Gain	Output Level	Drop Level
Amplifier		+32.0 dBmV	
100' .500 cable	1.0 dB	+31.0 dBmV	
2/20 Tap	.4 dB	+30.6 dBmV	+11.0 dBmV
600' .500 cable	6.0 dB	+24.6 dBmV	
2/14 Tap	1.0 dB	+23.6 dBmV	+10.6 dBmV
500" .500 cable	5.0 dB	+18.6 dBmV	
2/8 Tap	2.8 dB	+15.8 dBmV	+10.6 dBmV

All of the above figures agree with the earlier development process, but now we can clearly see the impact of each device inserted into the system and we have a continuous presentation of transmission signal level as the design is extended. Note that in both Figure 12-1 and in the above tabulation, the total transmission loss incurred from tap insertion losses is 4.2 dB.

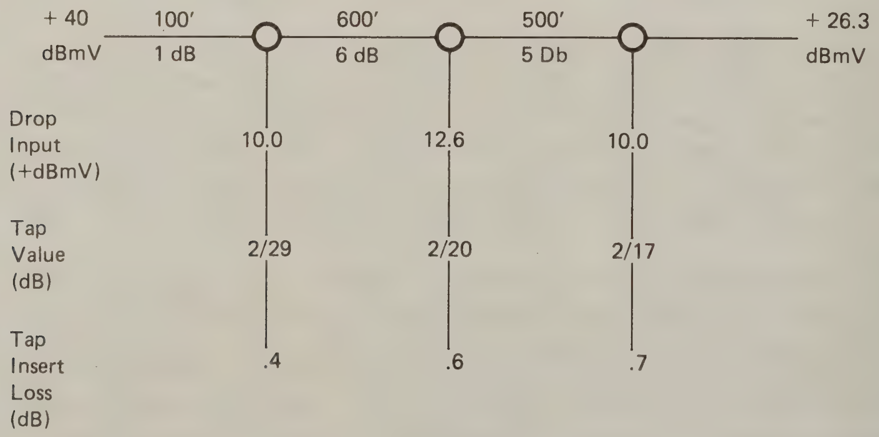


Figure 12-2 Tap Insertion Loss (medium RF levels)

Now, as is shown in Figure 12-2, we will repeat the entire process but we will assume that the input signal level to the cable section is +40 dBmV rather than the previous +32 dBmV. The tabulation technique should be useful here.

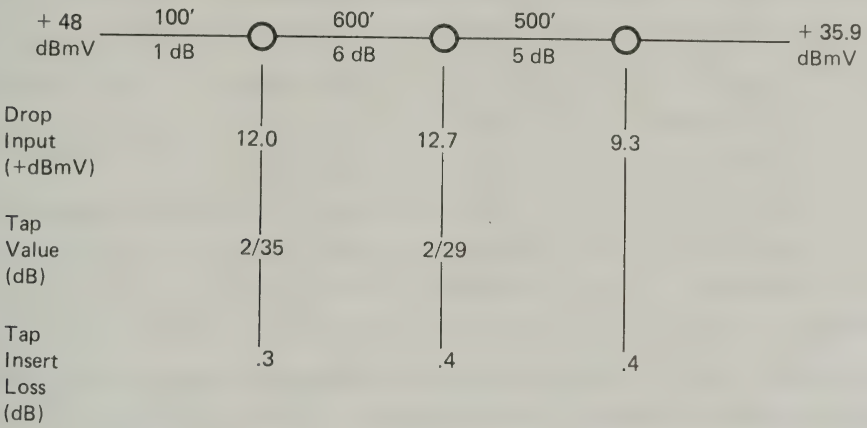


Figure 12-3 Tap Insertion Loss (high RF levels)

Device or Cable	Insert Loss/Gain	Output Level	Drop Level
Amplifier		+40.0 dBmV	
100" .500 cable	1.0 dB	+39.0 dBmV	
2/29 Tap	.4 dB	+38.6 dBmV	+10.0 dBmV
600’ .500 cable	6.0 dB	+32.6 dBmV	
2/20 Tap	.6 dB	+32.0 dBmV	+12.6 dBmV
500’ .500 cable	5.0 dB	+27.0 dBmV	
2/17 Tap	.7 dB	+26.3 dBmV	+10.0 dBmV

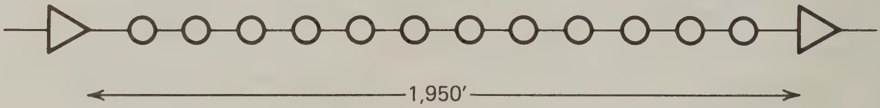
Note that in Figure 12-2, with a +40 dBmV input to the cable section, the total tap insertion loss presented is 1.7 dB. In the earlier example, the insertion loss was 4.2 dB. Figure 12-3 shows an even higher input signal level of +48 dBmV. The total tap insertion loss presented by Figure 12-3 is now only 1.1 dB.

The higher transmission levels permit greater usage of low insertion loss tap values. This is beneficial in extending the system since transmission losses (cable plus inserted devices) dictate amplifier spacing. We can use fewer amplifiers per given distance of tapped plant or, conversely, we can accommodate more taps in a given length of cable.

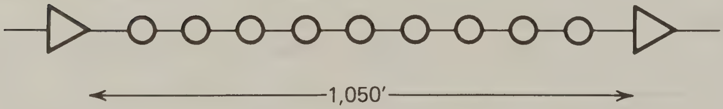
The tapping efficiency is higher when the system transmission levels are higher. Note that in all of the above examples, we met or exceeded our required +10 dBmV input to the service drop.

Device or Cable	Insert Loss/Gain	Output Level	Drop Level
Amplifier		+48.0 dBmV	
100' .500 cable	1.0 dB	+47.0 dBmV	
2/35 Tap	.3 dB	+46.7 dBmV	+12.0 dBmV
600' .500 cable	6.0 dB	+40.7 dBmV	
2/29 Tap	.4 dB	+40.3 dBmV	+11.7 dBmV
500' .500 cable	5.0 dB	+35.3 dBmV	
2/23 Tap	.4 dB	+34.9 dBmV	+12.3 dBmV

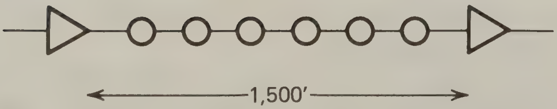
Our earlier discussions on noise and intermodulation distortion clearly showed the associated penalties of higher transmission levels. Engineering is a series of compromises, however, and we must trade off higher tapping efficiency with higher intermodulation distortion as the result of higher amplifier output levels.



Example A - 12 taps
(+48 out)



Example B - 9 taps
(+40 out)



Example C - 6 taps
(+32 out)

Figure 12-4 Tapping Efficiency

When a particular application can be characterized as requiring long cable routes with widely distributed and limited subscriber service taps, we might consider accepting the less efficient tapping of lower transmission levels if an attractive economy in system construction were produced. These conditions can be found in the rural applications that we will be discussing later.

In order to reinforce the previous examples, consider Figure 12-4 where comparison of operational transmission levels correlated with tap insertion losses is shown. The transmission levels shown were selected for illustrative purposes.

550 MHz Systems

The tabulation of data as a part of the system design process is a very practical way to lay out systems, and it is particularly useful in locating any errors that might be made or in any redesign efforts that might subsequently be required. Using the subscriber tap data presented earlier in this chapter as Table 12-1, let us develop the same system layout problems we just completed, using a 550 MHz system bandwidth.

For discussion purposes, we will assume the amplifier output levels are tilted 6 dB, that is, the output level at 550 MHz will be 6 dB higher than the output level at 50 MHz.

We will have to redesign the tabulation itself somewhat since we are now required to record all transmission losses and levels at two frequencies, not simply at one as in the earlier examples.

Device or Cable	Insert Loss/Gain (dB)		Output Level (+dBmV)		Drop Level (+dBmV)	
	50	550	50	550	50	550
Amplifier			26.0	32.0		
100' .500 cable	.52	1.85	25.5	30.2		
2/14 Tap	.70	1.30	24.8	28.9	10.9	14.2
600' .500 cable	3.12	11.1	21.7	17.8		
2/7 Tap	3.40	4.30	18.3	13.5	15.3	10.8
500' .500 cable	2.60	9.25	15.7	4.25		

SIGNAL LEVEL TOO LOW TO PROCEED WITH DESIGN

The design effort assumed the same tapping requirements as shown in Figure 12-1, but the values and transmission losses were different. Note that using a +32 dBmV input level to the cable section, the transmission losses at 550 MHz were such that we could not complete the design and serve the required three locations because the signal level simply was too low to proceed further.

Tapping insertion loss through the cable section is irrelevant since the cable plant could not be extended using this design anyway.

Device or Cable	Insert Loss/Gain (dB)		Output Level (+dBmV)		Drop Level (+dBmV)	
	50	550	50	550	50	550
Amplifier			34.0	40.0		
100' .500 cable	0.52	1.85	33.5	38.2		
2/23 Tap	0.30	0.80	33.2	37.4	10.2	14.2
600' .500 cable	3.12	11.1	30.1	26.3		
2/14 Tap	0.70	1.30	29.4	25.0	15.5	10.3
500' .500 cable	2.60	9.25	26.8	15.8		
2/4 Tap	-----	-----	-----	-----	23.4	12.1

We can make the same development using a +40 dBmV cable input level, and the problem addressed is similar to the one completed earlier for Figure 12-2 for a 300 MHz bandwidth.

Although we are now able to service all three tap locations, and to provide compliant signal levels to all service drops (+10 dBmV or higher), we were obliged to use a terminating subscriber tap as the last unit, and consequently the design as shown cannot be extended beyond the last service point. The cumulative tapping insertion loss becomes irrelevant if the system cannot be extended.

What happens when we raise the input signal level to the cable section to +48 dBmV, as we did earlier using Figure 12-3 for a 300 MHz system?

Device or Cable	Insert Loss/Gain (dB)		Output Level (+dBmV)		Drop Level (+dBmV)	
	50	550	50	550	50	550
Amplifier			42.0	48.0		
100' .500 cable	0.52	1.85	41.5	46.2		
2/29 Tap	0.30	0.70	41.2	45.3	12.1	15.2
600' .500 cable	3.12	11.1	38.1	34.4		
2/23 Tap	0.30	0.80	37.8	33.6	14.8	10.4
500' .500 cable	2.60	9.25	35.2	24.4		
2/12 Tap	1.10	2.30	34.1	22.1	23.5	12.4

Although we are able to serve all three taps using a +48 dBmV input level, and all drop cable input levels are above +10 dBmV and thus are fully compliant, note that the signal levels into the service drop at tap three are +23.5 dBmV at 50 MHz and +12.4 dBmV at 550 MHz. Depending upon the system specifications, these levels may not be acceptable since the differential between the two signals fed into the drop cable exceed 10 dB, actually the difference is 11.1 dB. However, we can extend the system beyond the third tap location.

We can see from this exercise, that the problems of broader bandwidth transmission systems (550 MHz) are more complex than in the limited bandwidth applications (300 MHz), but it is quite clear that higher transmission levels do improve the efficiency of system tapping, just as the earlier example in the 300 MHz system demonstrated. We can also see that along with the problems of higher losses at higher frequencies, some intermediate correction of system frequency response may be desirable or necessary if we are to present all signals to all subscriber terminals without gross variations in level. Even tilting amplifier outputs 6 dB could not reduce tap signal level variations to an acceptable level.

Intermediate (In-Line) Frequency Equalization

It is not the purpose of this text to establish or endorse particular transmission specifications, but to explain the problems and the corrective actions clearly enough so that any reader can effectively respond to any specific requirement. The question of what is an acceptable range of signal level variations at a subscriber terminal is a case in point.

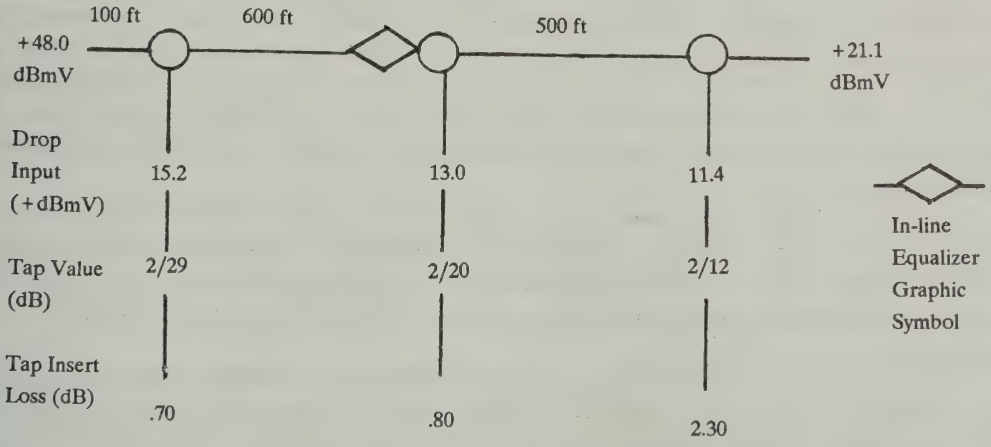


Figure 12-5 Intermediate (in-line) Equalization

In Figure 12-5 we show the same tapping problem we discussed earlier as a 300 MHz application, but in this figure we are showing all transmission losses for a 550 MHz system and we have inserted an in-line equalizer just ahead of the second tap.

We will develop a tabulated projection of the system as we did before, and note that all losses and levels up to the point where we inserted the in-line equalizer are just as they were earlier.

Device or Cable	Insert Loss/Gain (dB)		Output Level (+dBmV)		Drop Level (+dBmV)	
	50	550	50	550	50	550
Amplifier			42.0	48.0		
100' .500 cable	0.52	1.85	41.5	46.2		
2/29 Tap	0.30	0.70	41.2	45.3	12.1	15.2
600' .500 cable	3.12	11.1	38.1	34.4		
Equalizer	6.00	1.00	32.1	33.4		
2/20 Tap	0.40	0.80	31.7	32.6	12.6	13.0
500' .500 cable	2.60	9.25	29.1	23.4		
2/12 Tap	1.10	2.30	28.0	21.1	17.4	11.4

The equalizer is a passive device in a housing that is spliced into the coaxial cable, much as a tap would be. The transmission losses through this unit are 1 dB at 550 MHz and 6 dB at 50 MHz.

If we examine both tabulations, we see two beneficial effects produced by the insertion of the equalizer. The earlier example produced a differential between signal levels at the last tap output port, the point where cable extension began, of 12.0 dB, from 34.1 - 22.1 = 12.0 dB. This last example produces only 6.9 dB differential, from 28.0 - 21.1 = 6.9 dB. The signal level differentials at the tap output port that feeds the drop cable are reduced also. It was 11.1 dB from 23.5 - 12.4 = 11.1 dB. It now is only 6.0 dB from 17.4 - 11.4 = 6.0 dB.

The use of in-line equalizers does present a technically acceptable correction, but it also introduces costs, both to purchase the units and to splice them into the system with connectors. The use of such equalizers is generally restricted to systems that provide a transmission bandwidth in excess of 300 MHz, but the use of such units is not mandatory.

Note from Figure 12-5 that it is the cable that has introduced most of the signal level differential in the first place. The taps themselves, although they do individually contribute some response distortion, are not the major problem. If a particular system had a multiplicity of subscriber taps that were separated by only nominal lengths of cable, then the use of in-line equalizers may not be necessary even though the system might have a transmission bandwidth of 450 or 550 MHz. Such a situation might be encountered in urban systems where the area includes a lot of row house or town house types of buildings with short cable runs between taps.

It must be recognized that the distortion is less severe in systems that present less bandwidth and it gets progressively less tolerable as system bandwidth increases. At bandwidths that are only nominally high, perhaps 450 MHz would be an example, some system designers will endorse and use in-line equalizers exclusively in all situations while other engineers may not. It does not automatically follow that a system using such units is superior. The decision is a judgement, and in some cases there may be differences in system specifications that make it possible to not employ any-intermediate equalization at all.

System Design Calculations

Tabulating all data for system design calculations is both simple and helpful, and it is suggested that the reader adopt the use of such a design aid as a regular practice. With just a little thought, a form can be developed that is equally applicable to lower bandwidth, single frequency design work, or broader bandwidth work involving calculations at two frequencies. In the sample that follows, for example, for a 300 MHz design, only one set of figures would be entered for each line item.

The form need not actually specify a discrete frequency and thus could be used for any design efforts by simply entering the appropriate frequencies in the places provided. We present the following as one approach at such a form.

System Design Calculation Form

	Insert Loss/Gain (dB)		Output Level		Tap Level	
Item	MHz	MHz	MHz	MHz	MHz	MHz

The form might even be improved if space were provided for another vertical column on the right hand side where the signal level Delta or differential of the tap output levels at both frequencies could be calculated and entered. In broader bandwidth applications, we expect to have a specification imposed on the differential between two frequency tap outputs. By having space in the form to record the differential, we could quickly examine the design result for non-compliant entries.

Accommodating New Service Loads

In the system layout process after amplifier gain and operational signal levels have been determined, all transmission losses such as cable side lead feeds and subscriber tap insertion losses must be calculated, and as required, offsetting gain must be provided by inserting amplifiers. If a new transmission loss is subsequently introduced into a system already constructed, the effect will change transmission levels in part of the system and can degrade the end-of-system transmission performance.

Most initial layouts provide a service access point (tap or other feed) at every residence passed. These service points are actually installed and equipped during construction even though a subscription for service may be uncertain for every such tap. Regardless of what philosophy is followed in system design, almost every system will unavoidably encounter situations that require additional service points after the initial design and construction is completed. There are several techniques that can handle these situations, and some prudent expansion capability for growth can be incorporated into the initial design.

In Figure 12-6 we show a small section of a system including two amplifiers and two taps; the transmission levels were arbitrarily selected to be +8 and +40 dBmV respectively, thus the usable gain of each amplifier is +32 dB. These input and output levels and the amplifier gain, were established during the engineering phase of system design with due regard for the longest cable route required and the desired end-of-system transmission performance. Note that all drop cable inputs are at a compliant +10 dBmV level or higher.

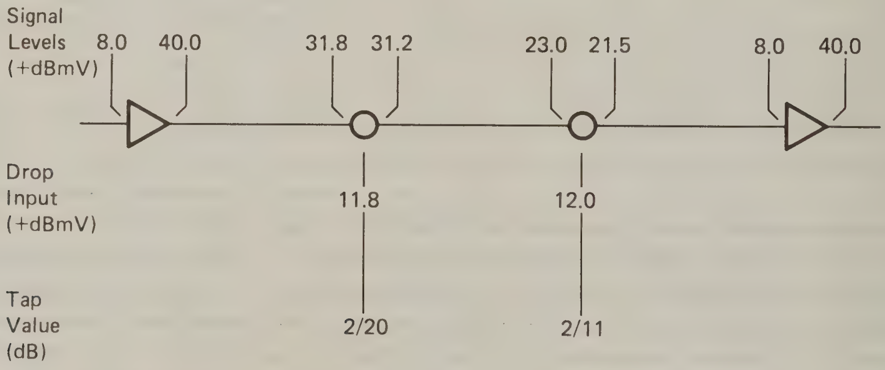


Figure 12-6 Initial Layout

In Figure 12-7 we have a requirement for a service drop feed that developed long after the initial system layout and construction was completed. The point along the cable section where the new service is required has been analyzed, and the signal level available at that point is +18 dBmV, as shown.

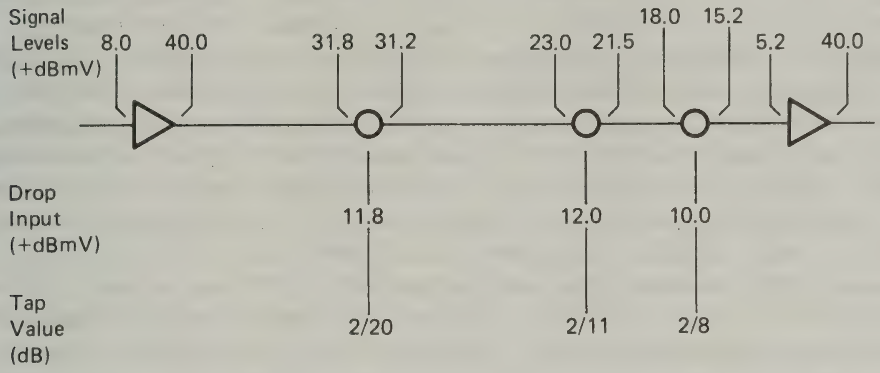

Signal
Levels
(+dBmV)
8.0
40.0
31.8
31.2
23.0
21.5
18.0
15.2
5.2
40.0
Drop
Input
(+dBmV)
11.8
12.0
10.0
Tap
Value
(dB)
2/20
2/11
2/8

Figure 12-7 Load Added (low RF level)

If we require +10 dBmV input to the service drop, a typical required level, then an 8 dB two-port tap could be cut into the in-place cable at this point. An 8 dB tap would introduce approximately 2.8 dB of insertion loss into the through cable. If we examine the input level presented to the next amplifier past the tap, we will find it 2.8 dB lower than the initial design and layout provided. The C/N ratio of this-particular amplifier would be 2.8 dB poorer than the original transmission engineering intended.

In a cascade of 25 or 30 amplifiers, this degradation in any single amplifier may or may not be perceptible at the end of the system. However, if we consider 10 or 15 such insertion losses over a period of time, at some point the end-of-system degradation will become intolerable. A planned program to accommodate subsequent subscriber taps or cable route feeds is essential during the transmission engineering and system layout stages of system design.

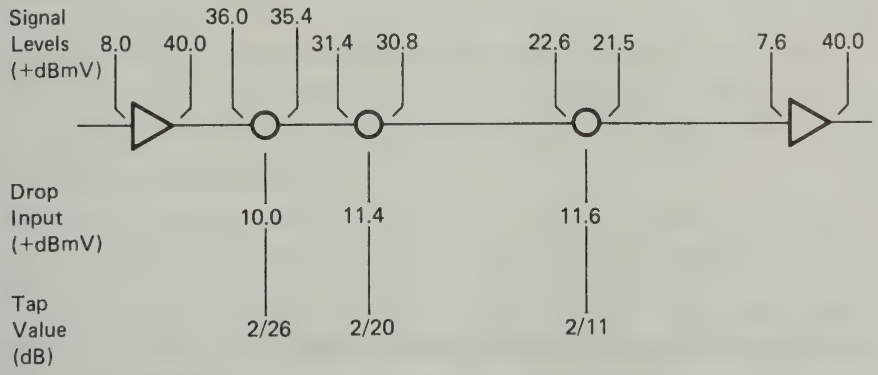

Signal
Levels
(+dBmV)
8.0
40.0
36.0
35.4
31.4
30.8
22.6
21.5
7.6
40.0
Drop
Input
(+dBmV)
10.0
11.4
11.6
Tap
Value
(dB)
2/26
2/20
2/11

Figure 12-8 Load Added (high RF level)

Examine Figure 12-8. Here we show another new service requirement, but at this new location the signal level available for tapping is +36 dBmV. Again requiring a +10 dBmV input to the service drop we can use a 26 dB two-port tap as the figure shows, but this tap introduces only 0.4 dB of insertion loss into the main cable. Note that all signal levels past the new tap point are now 0.4 dB lower. This not only includes the next amplifier input, which is +7.6 dBmV (down from +8 dBmV), but the service drop levels are also reduced. The degradation in C/N ratio is only 0.4 dB, which is relatively minor and in a long cascade of amplifiers would probably be quite acceptable, but some of the subscriber terminal signal levels may be put out of specification.

The point of this discussion is that the location of the new service point will have a good deal to do with its impact on end-of-system performance. In Figure 12-7, the C/N ratio was degraded 2.8 dB, while in Figure 12-8 it was degraded only 0.4 dB. The above examples show a single service drop as the new system load, but the problem is similar if the new load were a feed point for a new lateral cable run or a new residential development or apartment house, but if the new load is of this magnitude, the problem is somewhat simpler.

All we have to do is tap off enough RF energy from the main cable to provide a suitable input level to a new amplifier. Since amplifier input in our examples was specified to be +8 dBmV, this level can be tapped off using a directional coupler. A directional coupler will introduce significantly less insertion loss into the main cable as we learned in Chapter 3.

In every case where we insert new transmission loss into working CATV plant, some compromise, however slight, is imposed on system overall performance. Across a period of many years or periods of unusual growth, many such new loads could produce out-of-specification performance at the end of the system and/or at individual service drops within the system.

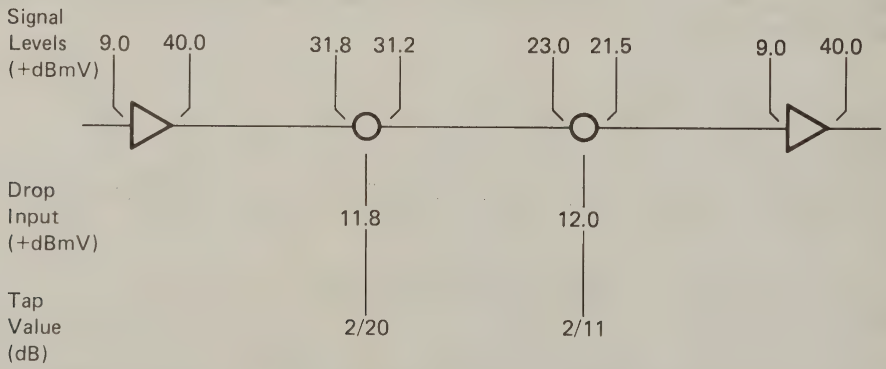


Figure 12-9 Short Spaced Amplifier

Reserve Gain Solution

In our examples, the initial system engineering established operational signal levels of +8 dBmV of input and +40 dBmV of output for each amplifier. To ensure end-of-system transmission quality even after subsequent transmission losses are inserted, we could simply reserve some of the amplifier gain in the layout process.

In Figure 12-9 we have the identical taps we had in Figure 12-6, but we have placed the second amplifier at a point where its input signal level is actually +9 dBmV, not +8 dBmV. This reduces the amplifier spacing by 1 dB but in our examples this is only 80 feet or so. The initial design was based upon satisfactory end-of-system performance with a +8 dBmV input level. With the reduced spacing shown in Figure 12-9, we would actually enjoy, initially, a 1 dB C/N ratio improvement by operating at a +9 dBmV input level.

The real significance is that in each and every cable section of the system, we can insert 1 dB of additional transmission loss and not compromise end-of-system performance at all. It did short space every amplifier 1 dB, but that would add only one amplifier to a system 30 amplifiers "deep." This may be an acceptabe penalty.

We might provide more than 1 dB of reserve gain in each cable section, but the cost penalty on the system would be more pronounced. Since we cannot predict where new service loads will actually develop, it seems reasonable to equally protect every cable section against such a possibility but limit the degree of such protection. If we could have predicted the new service loads, we would have made provision for them during the initial layout. The 1 dB figure was not derived casually but is in direct response to a technique of plant relief called "back feed" cabling.

Back-Feed Cable

In the event that the new service load is substantial or is located in the most awkward area of the cable section, and from Figure 12-7 we can identify that to be the area immediately preceding the next amplifier, we could insert a directional coupler at the amplifier output. This would provide a relatively high signal level feed point with a relatively low insertion loss penalty, surely a penalty within our 1 dB of reserve gain. This high signal level point can now be used to feed a limited section of parallel cable. Although the technique is called "back feed," it could equally, or also, feed a parallel cable running some distance forward of the amplifier location if some or all of the new service load were located in that area.

Since the amplifier output level is +40 dBmV, a 16 dB directional coupler with insertion loss penalty of only 0.6 dB could provide a very respectable +24 dBmV to feed the new, parallel cable run. The new load can be cut into this new cable, or existing taps in the main cable could be relocated on to this new cable. This would reduce the total tap loss in the main cable to accommodate new tap loads anywhere else within the original cable section.

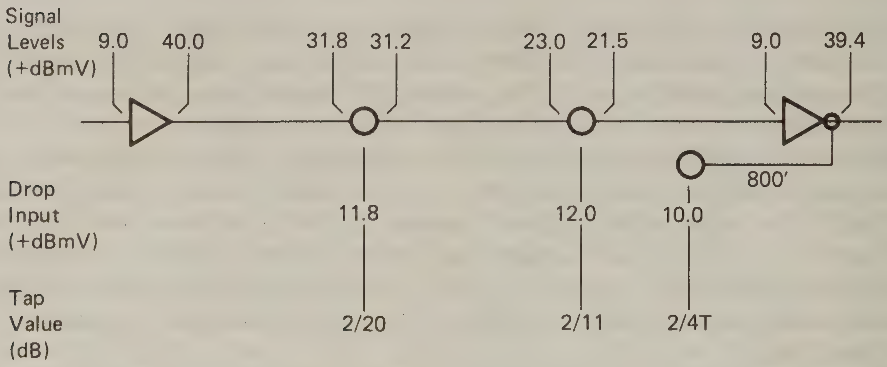


Figure 12-10 Back-feed Cable

Figure 12-10 shows the placement of the directional coupler, with the new feed point being utilized to accommodate a new tap load 800 feet ahead of the amplifier location. This would have been a very awkward new load to handle any other way. Note that this technique has preserved the next amplifier input level well above the designed +8 dBmV rather than let it drop to the undesirable +5.2 dBmV shown in Figure 12-7.

Allocating Reserve Gain

We have demonstrated that allocating some reserve gain prior to system layout will minimize the effect of new service loads. However, how we distribute the reserve gain has a great deal to do with how acceptable the new load will actually be.

In the example shown in Figure 12-8 we showed a tap inserted into the cable section at a point where the transmission levels were quite high. Though this minimized the effect on the next amplifier input level, there was still an effect. There was also a level change at the subscriber end of every service drop within that amplifier section beyond the point where the new tap was inserted.

In Figure 12-9 we had close spaced the next amplifier by 1 dB. Now any 1 dB insertion loss added to the cable section would not reduce the amplifier input below the design objective level of +8 dBmV, so there would be no out-of-specification performance at the end of the system. We would, however, still be changing the end-of-drop signal levels for all taps in place beyond the new service point within that cable section.

If we did not change the output level (operational level) from +40 dBmV, but assumed it to be only +39 dBmV for layout purposes, all service drop levels would initially by 1 dB higher.

This does no harm, and if we subsequently add 1 dB of new load, although all service drop levels would go down 1 dB, none would go out of specification. We could layout for a +39 dBmV output and locate the next amplifier at a +8 dBmV level point, but in initial operation, we will set the amplifier for +40 dBmV of output, producing a +9 dBmV input to the next amplifier.

This produces the same 1 dB reserve and imposes the same 1 dB spacing penalty, but now we can insert 1 dB of new loss anywhere, and no system specification will be violated including end of service drop levels. This technique produces the same cable section length as before, 31 dB of transmission loss.

Active Feeders

In a subsequent chapter of the text we will discuss in some detail the philosophy of trunk/feeder system design, but a brief introduction to feeder cable is appropriate here. It certainly is a basic alternative element in all designs.

We will define two types of feeder plant. The first is active transitioning from one operational signal level to new, higher levels of transmission. The second is passive and provides limited "off-route" service without any additional amplification at all.

In establishing an "active" feeder the intent is not only to provide a distinctly separate cable for accommodating service drops but to escalate the signal levels through this new "feeder" plant, thus improving tapping efficiency. This is accomplished by using any of several "bridging" amplifier techniques.

The transmission levels in the primary cable plant (the trunk cable) are not disturbed. The input RF feed for the bridging amplifier is accomplished through a directional coupler that imposes only nominal transmission loss to the trunk cable. However, the bridging amplifier is operated at substantially higher output levels than the trunk unit. Typical levels might be +32 dBmV for trunk output, and +48 or +50 dBmV for bridger output. Obviously this produces substantially higher intermodulation distortion in the bridger but we can tolerate this if we limit the cascade of such units.

In trunk/feeder systems the bridger is usually followed by two or three high-output level, high-distortion producing line extender amplifiers also. By careful design, the increased "feeder" distortion contribution is kept acceptable, in part because we limited the intermodulation distortion in all of the trunk amplifiers through conservatively low output levels.

Figure 12-11 shows a bridging amplifier incorporated into a trunk amplifier housing, a very common practice. This becomes only one power-consuming location and only one maintenance point also. Note that this type of station permits individual adjustment of trunk or feeder output signal levels since individual gain modules with individual gain controls are provided.

In Figure 12-12 we show an intermediate bridging amplifier located where no primary or trunk cable amplifier is required at all but where initiating feeder cables is necessary, and in Figure 12-13 we show a terminating bridger application where the trunk cable need not and does not extend past that particular equipment location.

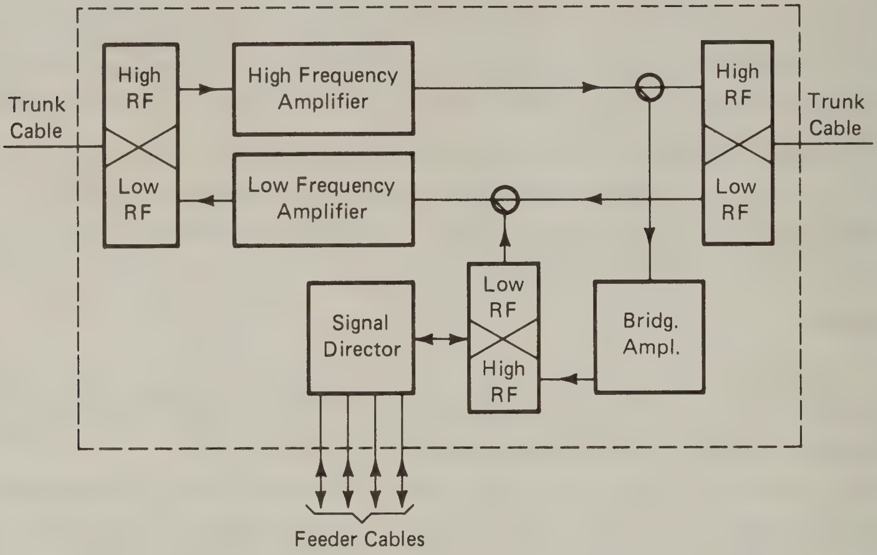

Trunk Cable
High RF
Low RF
High Frequency Amplifier
Low Frequency Amplifier
High RF
Low RF
Trunk Cable
Signal Director
Low RF
High RF
Bridg. Ampl.
Feeder Cables

Figure 12-11 Trunk Amplifier with Bridger Unit

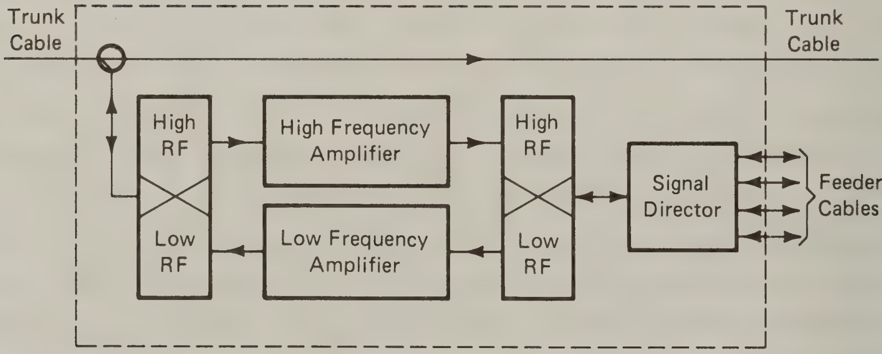

Trunk Cable
Trunk Cable
High RF
Low RF
High Frequency Amplifier
Low Frequency Amplifier
High RF
Low RF
Signal Director
Feeder Cables

Figure 12-12 Intermediate Bridger Amplifier

Bridgers can be equipped for return transmission capability as shown in Figures 12-11 to 12-13.

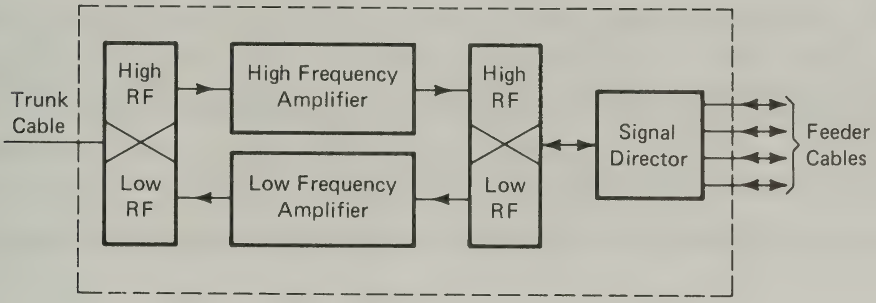

Trunk Cable
High RF
Low RF
High Frequency Amplifier
Low Frequency Amplifier
High RF
Low RF
Signal Director
Feeder Cables

Figure 12-13 Terminating Bridger Amplifier

Passive Feeders

Sometimes the service requirement (tap location) is only a short distance off the primary cable route. If the transmission level in the primary cable is sufficiently high, it may be possible to simply divert enough RF energy into the side lead (feeder) cable without installing an amplifier at all, as shown in Figure 12-14. All signal levels are included to facilitate reader analysis. This type of passive feeder may be more commonly encountered in rural applications.

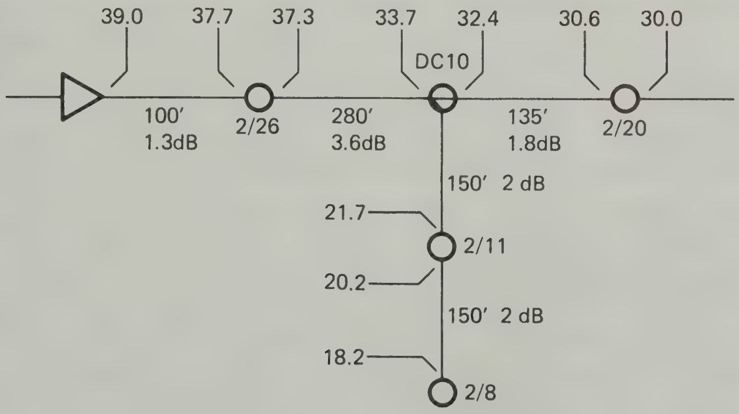

39.0
37.7
37.3
33.7
32.4
30.6
30.0
DC10
100′
1.3dB
2/26
280′
3.6dB
135′
1.8dB
2/20
150′ 2 dB
21.7
2/11
20.2
150′ 2 dB
18.2
2/8

Figure 12-14 Passive Feeder

Rural Feeders

In a subsequent chapter we will discuss rural applications in greater detail, but Figure 12-15 shows a side lead cable developed off a primary cable feed. This is somewhat analogous to Figure 12-10 except that in the rural system we will not be transitioning to a higher signal level on the lateral or feeder cable route at all.

We show it here for comparison but the terminology "feeder" is inappropriate if there is no change in operational signal levels. Actually, in a rural system, we will derive side lead cable routes in the same manner that we split trunk cable in trunk-plus-feeder systems. This will be explained in detail as we proceed through the text.

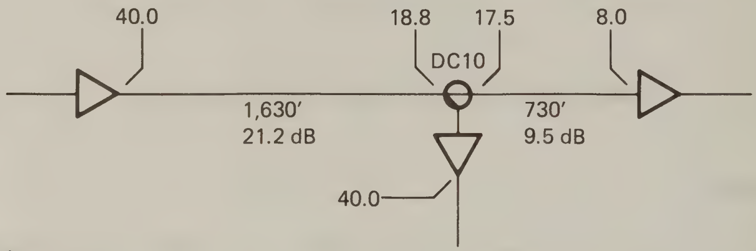


Figure 12-15 Rural Feeder

Summary

Some provision for new service loads is necessary whether the system is trunk-plus-feeder as in urban applications, or single cable as in rural applications. It has been general practice in the CATV industry to provide a service point feed for every existing residence in the service area, but in view of the potential for other services such as data transmission, alarm systems, etc., we may see more systems dedicating a service point and installing a tap for every commercial or industrial location also.

Where we reserved 1 dB in reducing the output level for layout purposes we provided the capability at every system amplifier to create a new cable feed through the use of a directional coupler. Managements may make individual policy decisions on whether or not these couplers are initially actually installed; but in any event, the subsequent installation would not require any changes or rearrangements of in-place plant or equipments. Neither would it introduce any out-of-specification performance or signal levels either at the subscriber end of service drops or at the end of the system.

We have shown that second cable feeds can be established at any or all amplifier locations within a system with no rearrangement of in-place plant, and without violating system specifications.

Some new service load requirements will be more awkward to handle than others and may also be less cost-effective, but all can and must be accommodated.

Chapter 13

Techniques of System Layout

The transmission engineering function of designing a CATV system involves such decisions as amplifier gain, operating transmission levels, tap output specifications, etc. Once these have been resolved, the actual layout of the system can proceed.

System Layout Defined

System layout is the process of overlaying on pole line or strand maps the actual cable routing, and the specifics of location, type, etc., of all equipments and devices required. Many individual judgments are required in the selection of tap values, insertion losses, etc., but it is largely a matter of simple arithmetic, repetitive calculations, and common sense. Although the methodology is not sophisticated, the actual layout will have a significant impact on system cost.

The product of the layout process is a system design transposed to drawings from which a bill of materials can be generated, and with which actual cable placement, splicing, and equipment installation can proceed. In addition, functions such as system powering, location of power supplies, and the selection of amplifier equalizers and attenuator pads can be completed.

For purposes of system layout, we can ignore such considerations as return loss specifications, mechanical features of equipments, etc., and assume that they have been, or will be, evaluated in the initial selection of a specific manufacturer's product. We need only address transmission losses and gain. We may also, at least in lower bandwidth system layouts, ignore loss or gain at any except the highest transmission frequency planned since this is the worst-case transmission loss.

When a substantial amount of layout work is involved, the process can be facilitated with computer-assisted procedures, and most manufacturers offer layout services done in this manner. However, it is still necessary to understand the layout process.

Even when a system has been designed, laid out, and constructed, operating staff is frequently called upon to design plant additions and extensions, and some understanding of layout will also be helpful in trouble analysis.

Perhaps the simplest way to demonstrate the layout process is by example. We will include the calculations required, and there are several examples where alternative solutions are presented. We will also utilize the tabulation design technique that we introduced in the last chapter, since this is a very practical method for all system layout work.

Splitters and Directional Couplers

In Figure 13-1 we see a common requirement where a single cable must provide signal input to two divergent cable routes. If we assume the RF energy available in the single cable should be equally divided into both cables, the device that must be employed is called a splitter which, by definition, divides its input equally across two outputs.

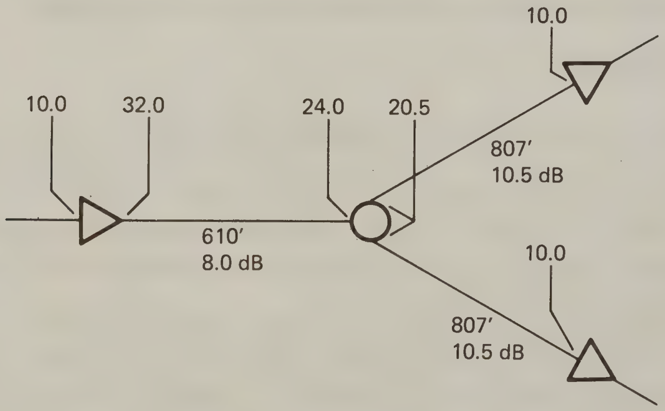
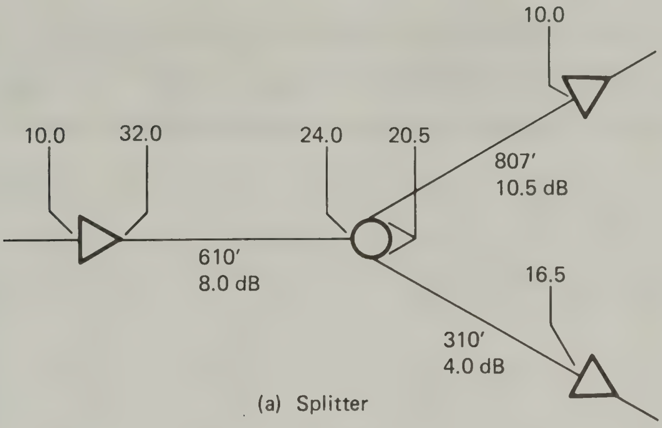
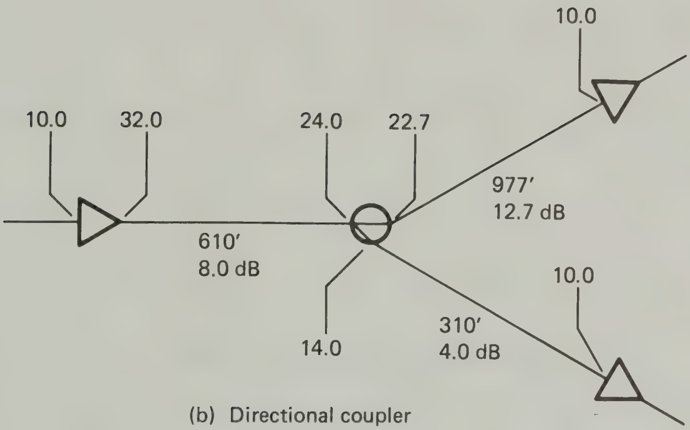


Figure 13-1 Splitter

Both operating signal levels and cable loss must be determined for the highest transmission frequency. We will arbitrarily assume this to be 300 MHz, and at this frequency, cable loss is taken to be 1.31 dB per 100 feet. We will use +10 dBmV of input and +32 dBmV of output as preestablished amplifier levels for this example. The question to be resolved is where to locate the first amplifier on each of the divergent cables after the splitter. As shown in Figure 13-1, each amplifier can be located 807 feet beyond the splitter, and a total of 1,417 feet from the preceding amplifier. Note the splitter loss is given to be 3.5 dB.


10.0
10.0
32.0
24.0
20.5
807′
10.5 dB
610′
8.0 dB
16.5
310′
4.0 dB

(a) Splitter


10.0
10.0
32.0
24.0
22.7
977′
12.7 dB
610′
8.0 dB
10.0
14.0
310′
4.0 dB

(b) Directional coupler

Figure 13-2 Splitter versus Coupler

In Figure 13-2a we see a situation where it is desirable, or necessary, to locate one amplifier only 310 feet beyond the splitter. In an actual system, such a location might be dictated by the need for feeder cable origination at that point. We see that a splitter does accomplish the required feed, but it provides a +16.5 dBmV amplifier input, a higher level than necessary. We could simply pad this down to the required +10 dBmV, but in Figure 13-2b we see a more efficient solution.

In Figure 13-2b we use a 10 dB directional coupler instead of a splitter. This produces the required +10 dBmV of input at the specified amplifier location 310 feet away. On the second radial cable route, however, the spacing to the next amplifier has been extended from the previous 807 feet to 977 feet.

Note that we have still provided the required +10 dBmV input to this unit. Thus, the directional coupler has produced fully compliant transmission levels, but extended the one amplifier spacing by 170 feet (977 - 807 = 170). In a long system, several similar situations might perhaps reduce the total required amplifier cascade.

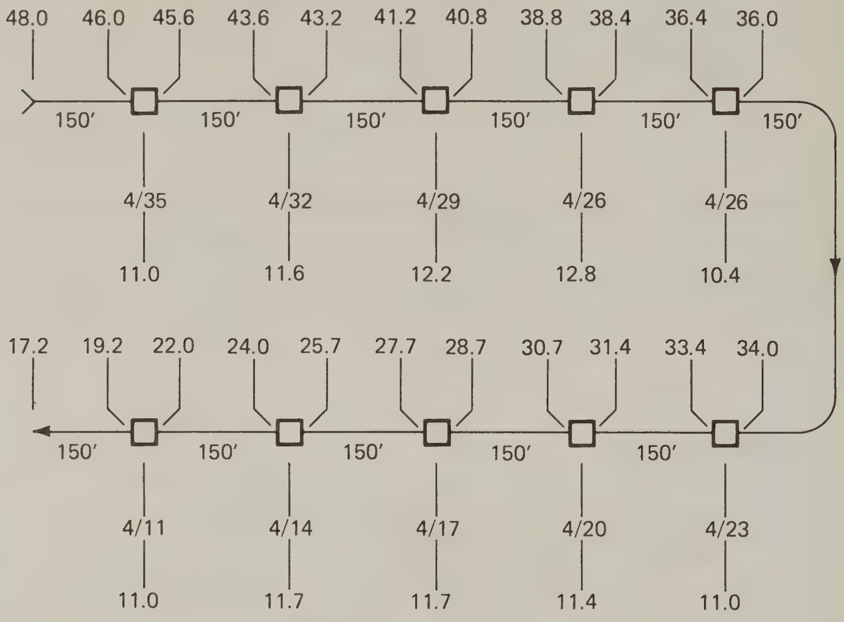

48.0
46.0
45.6
43.6
43.2
41.2
40.8
38.8
38.4
36.4
36.0
150′
150′
150′
150′
150′
150′
4/35
4/32
4/29
4/26
4/26
11.0
11.6
12.2
12.8
10.4
17.2
19.2
22.0
24.0
25.7
27.7
28.7
30.7
31.4
33.4
34.0
150′
150′
150′
150′
150′
4/11
4/14
4/17
4/20
4/23
11.0
11.7
11.7
11.4
11.0

Figure 13-3 Subscriber Tap Selection

Selecting Subscriber Tap Values

There is nothing particularly difficult about selecting tap values, but a simple exercise in doing so will reinforce our understanding of the process. In Table 13-1 we repeat the tap value chart we presented earlier in Chapter 3. Keep in mind that this table, and these examples, all assume an upper transmission frequency limit of 300 MHz. These values are for one particular manufacturer's equipment, and other suppliers may provide a slightly different sequence in tap values, that is, 7, 10, 13, 16 dB, etc., but the selection process is precisely the same.

In Figure 13-3 we show a line extender amplifier operating at +48 dBmV of output. We will use 1.31 dB per 100 feet of cable for loss, and specify a +10 dBmV of output to each service drop. Tap spacing is taken to be 150 feet, which is about 2 dB of cable loss.

Table 13-A Typical Subscriber Tap Values

No. of Outputs	Loss to Tap (dB)	Insertion Loss (dB)	Tap to Output Isol. (dB)
2T	4	---	---
2	8	2.8	23
2	11	1.5	26
2	14	1.0	29
2	17	0.7	32
2	20	0.6	35
2	23	0.4	38
2	26	0.4	41
2	29	0.4	44
2	32	0.4	47
4T	7	---	---
4	11	2.8	26
4	14	1.7	29
4	17	1.0	32
4	20	0.7	35
4	23	0.6	38
4	26	0.4	41
4	29	0.4	44
4	32	0.4	47
4	35	0.4	50

At the input to the first tap, the level is +46 dBmV as the figure shows. A four-port 35 dB tap will produce +11 dBmV of input to the service drop, since the input is +46 dBmV and the loss to the tap in such a unit is 35 dB. This tap is identified in Table 13-1 to have an insertion loss of 0.4 dB, so the level leaving the tap would be +45.6 dBmV, as shown. Given 2 dB of cable loss, the input to the second tap would be +43.6 dBmV, as shown. A 32 dB tap used here will provide a +11.6 dBmV to the service drop, and impose 0.4 dB loss to the through cable. Thus, the level leaving this tap is +43.2 dBmV, as shown. We can tabulate this development as follows:

Device or Cable	Insert Loss/Gain (dB)	Output Level (+dBmV)	Drop Level (+dBmV)
Amplifier		48.0	
150' .500 cable	2.0	46.0	
4/35 Tap	0.4	45.6	11.0
150' .500 cable	2.0	43.6	
4/32 Tap	0.4	43.2	11.6
150' .500 cable	2.0	41.2	
4/29 Tap	0.4	40.8	12.2
150' .500 cable	2.0	38.8	
4/26 Tap	0.4	38.4	12.8
150' .500 cable	2.0	36.4	
4/26 Tap	0.4	36.0	10.4
150' .500 cable	2.0	34.0	
4/23 Tap	0.6	33.4	11.0
150' .500 cable	2.0	31.4	
4/20 Tap	0.7	30.7	11.4
150' .500 cable	2.0	28.7	
4/17 Tap	1.0	27.7	11.7
150' .500 cable	2.0	25.7	
4/14 Tap	1.7	24.0	11.7
150' .500 cable	2.0	22.0	
4/11 Tap	2.8	19.2	11.0
150' .500 cable	2.0	17.2	

Of course the spacing distances shown here could have been random, and in an actual layout effort, would have been taken directly off a pole line or strand map. The types of taps required could have been random also, that is, a two-port tap could have been immediately followed by a four-port unit, or any particular sequence could be handled. The tabulation technique, and it could be thought of as a layout form, would be equally useful in any case. Note that a more sophisticated form is required for wider bandwidth layouts, because we must tabulate two transmission frequencies in such cases.

The tap value selections are dictated by the transmission level at the tap location and by the service drop input specification in every case. Examine the fifth tap inFigure 13-3. The input is shown to be +36.4 dBmV. To produce a specified +10 dBmV or higher input to the service drop, we utilized a four-port 26 dB tap which produced a service drop input level of +10.4 dBmV.

The layout proceeds in this fashion until the signal level in the through cable becomes too low to tap, or until this level is reduced to the system design input requirement for line extender amplifiers, whichever comes first. The signal level will be too low to tap when it is so low that no tap value can produce the required +10 dBmV.

For example, if the signal level in the cable were +14 dBmV, the smallest value four-port tap we have available is an 11 dB unit. If we used this tap with an input of +14 dBmV, the service drop would receive a +3 dBmV input only, which is not permitted by the specifications. At this point, we must insert another amplifier if we are to proceed further with the feeder cable.

Obviously a system cannot be efficiently laid out in random sections, but must be approached from the head end or point of origin and proceed out toward the most distant service point. Side lead or divergent cable routes ought to be designed as they are encountered, and not after the main cable route has been laid out, because it may be possible to accommodate some side leads passively (without using any amplifier at all).

The tabulation technique for system layout may appear to be cumbersome and time consuming, but it is a very practical method. Often, when doing a lot of layout work, small errors creep into the process. If the tabulation technique has been used, it is a relatively simple matter to check over the work and rapidly locate any such errors. Also, sometimes it is necessary to redesign a short section after finding out that it cannot be extended to all the required service locations. This would become evident only after the layout had been completed.

With the tabulation method, it is a simple matter to substitute a larger size cable, which introduces less transmission loss, and reexamine the original layout. It is suggested that a simple form be developed for this method and that it be used in all system layout work, regardless of the transmission bandwidth of the application being addressed.

The last example of layout, using the tabulation form, was obviously a 300 MHz application. For instructional purposes, using the form, let us design the same section for a 550 MHz system. We will assume that feeder amplifier input is specified to be +17 dBmV at 550 MHz, and that amplifier output will be +47 dBmV at 550 MHz and +37 dBmV at 50 MHz, a typical set of values in an urban system today. We will not only specify tap output requirements to be minimum signal level of +7 dBmV, we will also stipulate that the signal level differential between the high frequency carrier (550 MHz) and the low frequency carrier (50 MHz) cannot exceed 10 dB. Cable loss is assumed to be 0.52 dB per 100 feet at 50 MHz and 1.85 dB per 100 feet at 550 MHz. All tap losses are taken from Table 12-A in Chapter 12 for 550 MHz type taps.

Since the reader is now thoroughly familiar with the tabulation form for system layout, we need not present any drawing of the application at all, but the spacings shown in Figure 13-3 apply.

Note that we are fully compliant with all tap output specifications, since no tap output is below +7.9 dBmV in amplitude, where spec required more than +7.0 dBmV, and the worst case differential between signal levels at tap outputs is 7.7 dB, where spec limited this to 10 dB. To comply with the required amplifier input level of +17 dBmV, we had to insert another feeder amplifier 35 feet past the seventh subscriber tap, giving an amplifier spacing between these two feeder units of 1,085 feet.

Device or Cable	Insert Loss/Gain (dB)		Output Level (+dBmV)		Drop Level (+dBmV)	
	50	550	50	550	50	550
Amplifier			37.0	47.0		
150' cable	0.78	2.80	36.2	44.2		
4/26 Tap	0.30	0.75	35.9	43.5	10.0	17.7
150' cable	0.78	2.80	35.1	40.7		
4/26 Tap	0.30	0.75	34.8	40.0	8.9	13.5
150' cable	0.78	2.80	34.0	37.2		
4/23 Tap	0.30	1.30	33.7	35.9	10.3	13.1
150' cable	0.78	2.80	32.9	33.1		
4/23 Tap	0.30	1.30	32.6	31.8	9.5	9.0
150' cable	0.78	2.80	31.8	29.0		
4/20 Tap	0.60	1.10	31.2	27.9	11.7	8.8
150' cable	0.78	2.80	30.4	25.1		
4/17 Tap	0.90	1.60	29.5	23.5	13.2	8.3
150' cable	0.78	2.80	28.7	20.7		
4/12 Tap	2.30	3.00	26.4	17.7	16.6	7.9
35' cable	0.27	0.64	26.1	17.1		
Amplifier						

Note also that no in-line equalizer was required in this example to meet specifications, largely due to the 10 dB signal tilt that was provided in the previous amplifier output levels. To demonstrate the use of an in-line equalizer, let us assume all requirements are as before, but now we will tilt the amplifier output only 6 dB, providing +47 dBmV output on 550 MHz, and +41 dBmV output on 50 MHz.

Note that we are fully compliant with all tap output specifications, since no tap output is below +7.7 dBmV in amplitude, where spec required more than +7.0 dBmV, and the worst case differential between signal levels at tap outputs is 7.7 dB, where spec limited this to 10 dB. To comply with the required amplifier input level of +17 dBmV, we had to insert another feeder amplifier 64 feet past the seventh subscriber tap, giving an amplifier spacing between these two feeder units of 1,114 feet.

Note that an in-line equalizer was required in this example to meet specifications, largely due to the 6 dB signal tilt that was provided in the previous amplifier output levels. At the seventh tap location we tried to use a 4/14 tap, but the tap output levels were more than 10 dB different in amplitude, and so were out of specification. We left the notation in place and underlined it to call your attention to it, but in actuality, to make the design fully compliant, we had to insert an in-line equalizer, which changed the next tap value to a 4/12 as shown in the tabulation. Note that both of the examples given here are fully compliant with all specifications.

Device or Cable	Insert Loss/Gain (dB)		Output Level (+dBmV)		Drop Level (+dBmV)	
	50	550	50	550	50	550
Amplifier			41.0	47.0		
150' cable	0.78	2.80	40.2	44.2		
4/29 Tap	0.30	0.40	39.9	43.8	10.6	14.0
150' cable	0.78	2.80	39.1	41.0		
4/29 Tap	0.30	0.40	38.8	40.6	9.5	10.8
150' cable	0.78	2.80	38.0	37.8		
4/26 Tap	0.30	0.75	37.7	37.0	11.8	11.3
150' cable	0.78	2.80	36.9	34.2		
4/26 Tap	0.30	0.75	36.6	33.5	10.7	7.7
150' cable	0.78	2.80	35.8	30.7		
4/23 Tap	0.30	1.30	35.5	29.4	12.4	7.9
150' cable	0.78	2.80	34.7	26.6		
4/17 Tap	0.90	1.60	33.8	25.0	17.5	9.8
150' cable	0.78	2.80	33.0	22.2		
4/14 Tap	1.50	2.00	31.5	20.2	19.2	8.0
Equalizer	6.00	1.00	27.0	21.2		
4/12 Tap	2.30	3.00	24.7	18.2	14.9	8.4
64' cable	.33	1.18	24.4	17.0		
Amplifier						

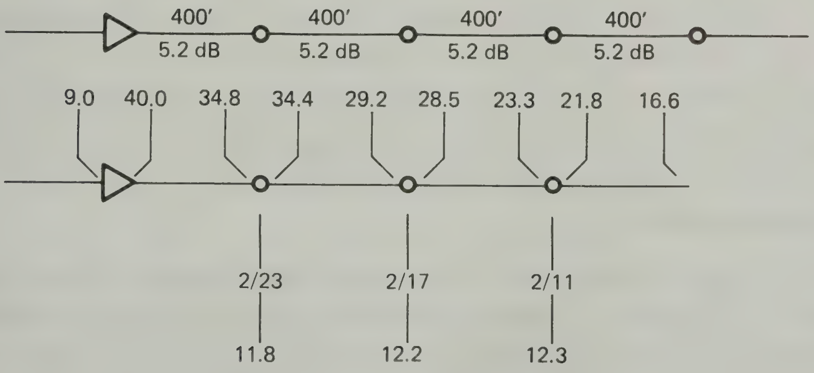

400'
5.2 dB
400'
5.2 dB
400'
5.2 dB
400'
5.2 dB
9.0
40.0
34.8
34.4
29.2
28.5
23.3
21.8
16.6
2/23
2/17
2/11
11.8
12.2
12.3

Figure 13-4 Tap Selection

Rural System Design

In Figure 13-4 we show a requirement for four two-outlet taps spaced 400 feet apart. Assume +10 dBmV is the required input to all service drops as before, and that this is a rural system using +9 dBmV input and +40 dBmV output at all amplifiers. Cable loss is taken to be 1.31 dB per 100 feet, as before. The input signal levels to all taps are shown, along with tap values selected, and the signal levels presented to the service drop cables. Note that all service drop inputs are fully compliant (+10 dBmV or greater). As an instructional exercise, we will tabulate the layout in Figure 13-4.

Device or Cable	Insert Loss/Gain (dB)	Output Level (+dBmV)	Drop Level (+dBmV)
Amplifier		40.0	
400' .500 cable	5.2	34.8	
2/23 Tap	0.4	34.4	11.8
400' .500 cable	5.2	29.2	
2/17 Tap	0.7	28.5	12.2
400' .500 cable	5.2	23.3	
2/11 Tap	1.5	21.8	12.3
400' .500 cable	5.2	16.6	

SIGNAL LEVEL TOO LOW TO PROCEED WITH DESIGN

At the fourth tap location we have a bit of a problem. Note in the tabulation or in Figure 13-4 that the transmission level at this point is +16.6 dBmV. From Table 13-A we see that the smallest two-port tap value at our disposal is an 8 dB tap. We cannot use the 4 dB tap because it is terminating and can only be used at the end of cable leads. If we require a +10 dBmV level to the service drop, and can only use an 8 dB tap, we cannot tap the cable at all whenever the transmission level falls below +18 dBmV. There are several options we might consider in this situation.

Using a Splitter as a Tap

By using a splitter that has 3.5 dB loss to each output instead of using a tap, we can provide a +13.1 dBmV of input to the service drop that is fully compliant, as shown in Figure 13-5. The level leaving the splitter is +13.1 dBmV on the main cable also. Since we required +9 dBmV of input to each amplifier, we can locate the next amplifier 4.1 dB away, or 313 feet as the figure shows.

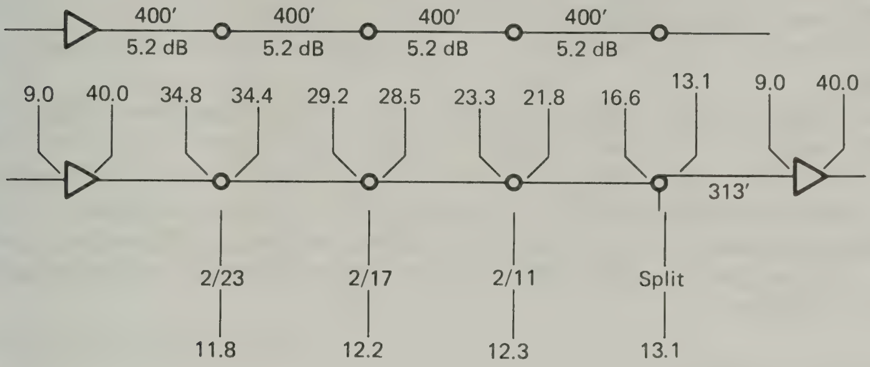

400′
5.2 dB
400′
5.2 dB
400′
5.2 dB
400′
5.2 dB
9.0
40.0
34.8
34.4
29.2
28.5
23.3
21.8
16.6
13.1
9.0
40.0
313′
2/23
2/17
2/11
Split
11.8
12.2
12.3
13.1

Figure 13-5 Splitter/Tap

Note that this technique, while meeting signal level requirements, provides only a single feed for service drop connection, and a splitter does not provide the inherent isolation for the terminal equipment that a tap does. This may be a reasonable violation of normal practice if only one isolated residence requires service, but if an additional new service load develops later, a back-feed cable would be more technically acceptable. However, this approach does postpone any back-feed cable costs until any new load actually develops, and in smaller, more economically marginal systems, this approach might be considered.

Back Feed Technique

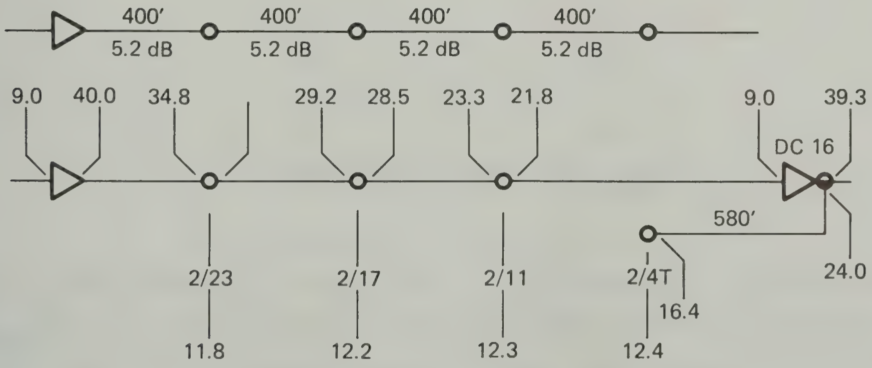

400′
5.2 dB
400′
5.2 dB
400′
5.2 dB
400′
5.2 dB
9.0
40.0
34.8
29.2
28.5
23.3
21.8
9.0
39.3
DC 16
580′
2/23
2/17
2/11
2/4T
16.4
24.0
11.8
12.2
12.3
12.4

Figure 13-6 Back-feed Cable

In Figure 13-6 we have placed a parallel cable to feed signal back to the required tap location from the next amplifier location. The signal level in the main cable at the required tap location was +16.6 dBmV, from Figure 13-3. Since we require +9 dBmV of input to each amplifier, we can locate the next amplifier 7.6 dB or 580 feet past the tap location.

At the output of this amplifier we will insert a DC-16 directional coupler. Since the amplifier output is +40 dBmV this will provide a +24.0 dBmV signal level input to the parallel back-feed cable. This will deliver a +16.4 dBmV level at the required tap location as the figure shows, and if we use a 2/4T 4 dB terminating tap, the input level to the service drop will be +12.4 dBmV. Note that the 16 dB coupler introduced 0.7 dB loss into the main cable, so the signal level applied to the next cable section is +40 - 0.7 = +39.3 dBmV.

Close-Spacing Amplifiers

A third solution is shown in Figure 13-7. We simply close-spaced the next amplifier by moving it back to the required tap location. The input to the amplifier will be higher than required (+16.6 dBmV instead of +9 dBmV), but we can simply pad this down to provide proper input to the gain module itself. Now we place a tap at the amplifier output, a 29 dB tap will do nicely, and the input to the next cable section will be +40 - 0.4 = +39.6 dBmV.

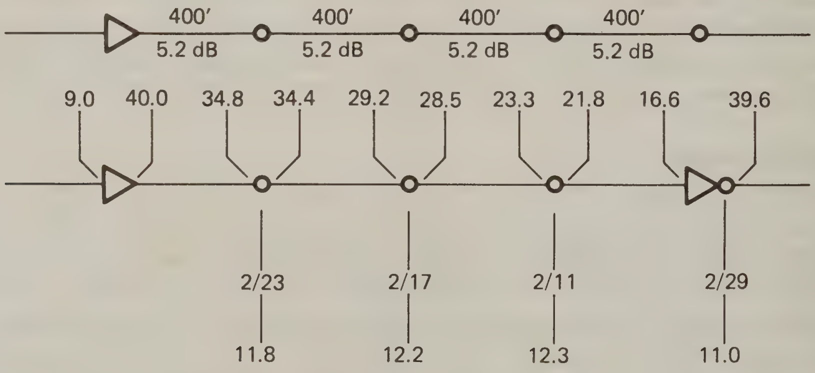


Figure 13-7 Close Spaced Amplifier

This technique is quite attractive in that it requires no parallel cable placement at all. It does sacrifice some amplifier spacing, however. When the cable route requires no long extension as in the "in town" sections of smaller systems, for example, close-spacing can be a preferred alternative to back-feed cabling. In very long rural routes, however, if several units are close-spaced in this manner, it may add an amplifier or two to the overall amplifier cascade, making it less attractive.

A comparison of the three techniques may help emphasize the differences:

Solution	Amplifier Spacing Achieved
Splitter tap	1,913 ft.
Back-feed cable	2,180 ft.
Close-spacing	1,600 ft.

If only a few locations on the cable route are involved, the reduction in amplifier spacing may well be the most satisfactory technique. If only occasional situations are involved, the splitter solution will reduce costs and minimize the spacing penalty.

Examples of System Layout

To develop some facility in layout, and to demonstrate the trade-offs and judgments to be considered, we have prepared two examples of awkward situations that might well be encountered in actual systems. We also include a critique of each alternative solution.

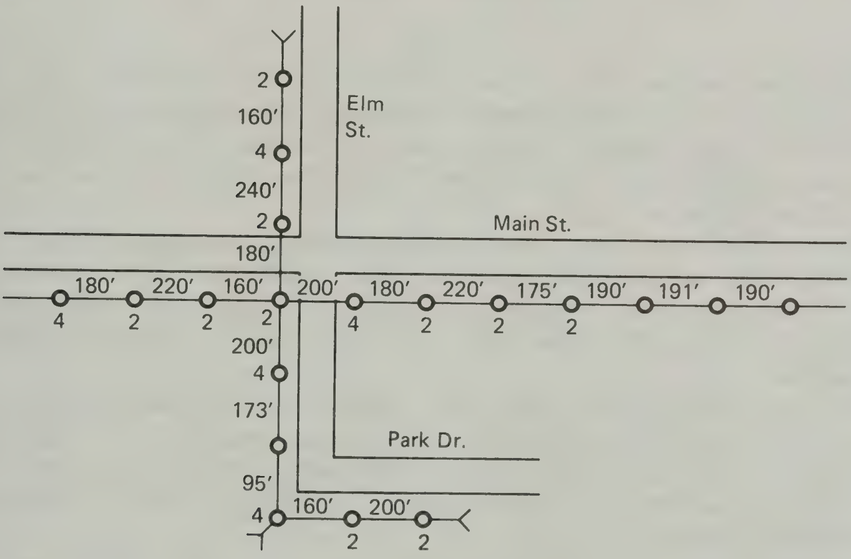

2
160′
Elm St.
4
240′
2
Main St.
180′
180′
220′
160′
200′
180′
220′
175′
190′
191′
190′
4
2
2
2
4
2
2
2
200′
4
173′
Park Dr.
95′
4
160′
200′
2
2

Figure 13-8 Layout Example 1

Example 1

In Figure 13-8 we show a section of a strand map on which a layout must be made. We assume an amplifier is located at the pole on the far left of the drawing.

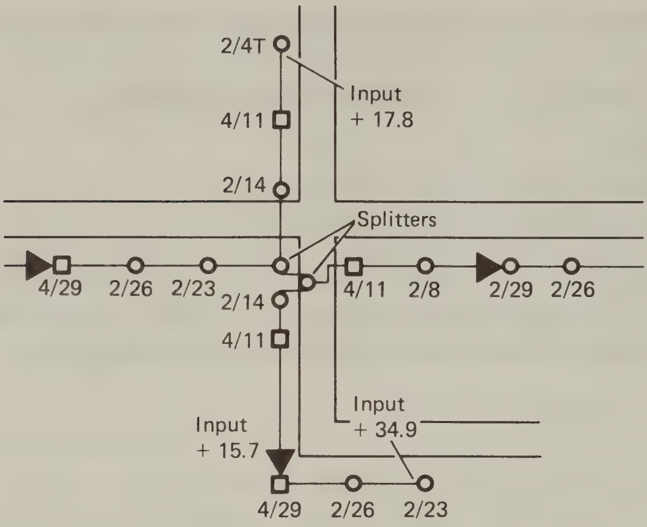


Figure 13-9 Splitter Layout

We further assume that its output level will be +40 dBmV. The single digit numbers adjacent to each pole denote the number of service drops to be fed at that location, and all span distances between poles are shown in feet. To clarify the layout drawing, the span distances will be deleted from Figure 13-9. We will assume cable loss to be 1.2 dB per 100 feet of length.

Figure 13-9 shows a layout utilizing two splitters at the intersection of Elm and Main Streets with an amplifier required at the intersection of Elm Street and Park Drive. By calculating cable loss for each pole span length, the reader can, and is encouraged to, develop the transmission levels throughout the layout and verify all tap value selections.

We strongly suggest that the reader utilize the tabulation technique here. This exercise will be helpful in understanding the process completely. It is not particularly complicated or sophisticated, but complete familiarity with the procedure is desirable. Note that all signal levels are fully compliant, including the service drop input levels, all +10 dBmV or higher.

Examine Figure 13-10. This is precisely the same system section, and again all signal levels meet all specifications. However, by repositioning the amplifier to the intersection of Elm and Main Streets, we were able to tap the through cable with a directional coupler (20 dB) rather than a splitter. Note that the second amplifier on the main cable route (Main Street) is now located three pole spans (571 feet) farther along Main Street than it was in the earlier solution.

In both solutions, the equipment costs are about the same. Due to the length and tap loading of the side lead cable runs, we could not eliminate an amplifier.

However, by simply repositioning the amplifier, which we were obliged to purchase anyway, we increased the main cable amplifier spacing by 571 feet at no additional cost. Again, in both cases, all system level specifications were met. Quite obviously, in this example the directional coupler layout is more efficient.

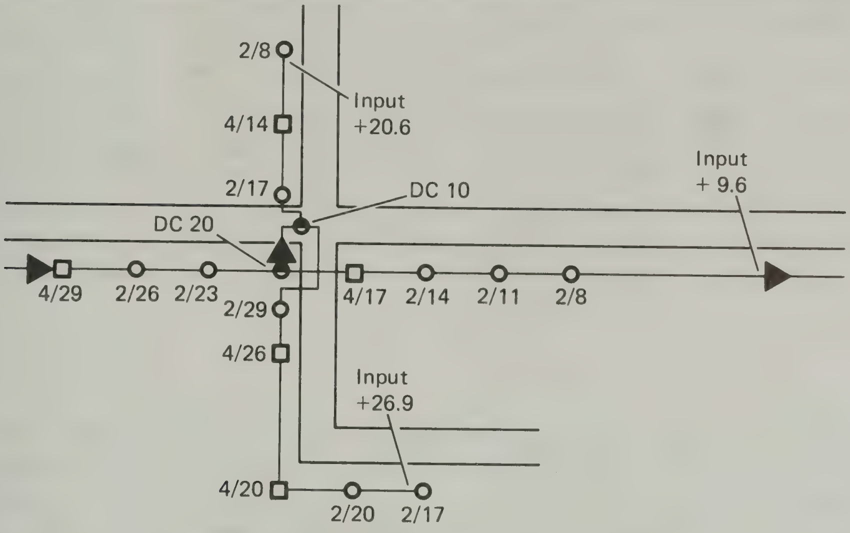

2/8
Input
+20.6
4/14
2/17
DC 10
Input
+ 9.6
DC 20
4/29
2/26
2/23
2/29
4/17
2/14
2/11
2/8
4/26
Input
+26.9
4/20
2/20
2/17

Figure 13-10 Directional Coupler Layout

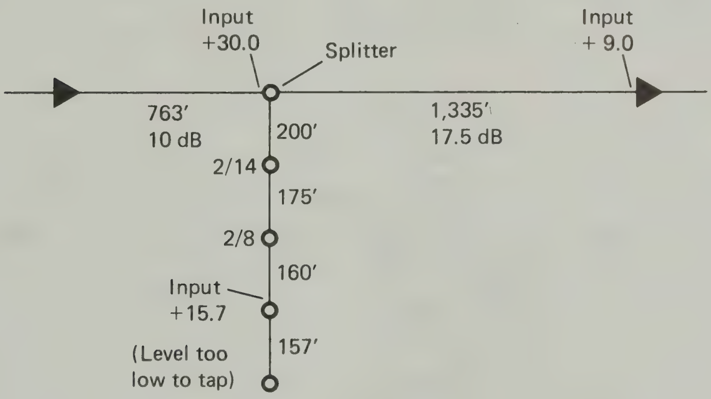

Input
+30.0
Splitter
Input
+ 9.0
763′
10 dB
200′
1,335′
17.5 dB
2/14
175′
2/8
160′
Input
+15.7
157′
(Level too
low to tap)

Figure 13-11 Splitter Layout

Example 2

In Figure 13-11 we see a short, side lead route at a point where the main cable signal level is +30 dBmV.

Our initial design attempt was to feed the side lead by inserting a splitter in the through (main) cable route, but we found the signal level on the side lead too low to be able to serve the last two service points, as the figure shows. We will now attempt to serve the side lead passively, without using an amplifier.

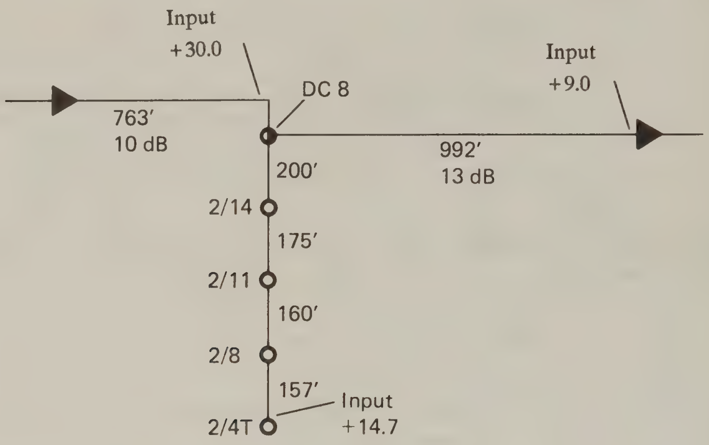

Input
+30.0
DC 8
Input
+9.0
763′
10 dB
200′
992′
13 dB
2/14
175′
2/11
160′
2/8
157′
Input
+14.7
2/4T

Figure 13-12 Directional Coupler Layout

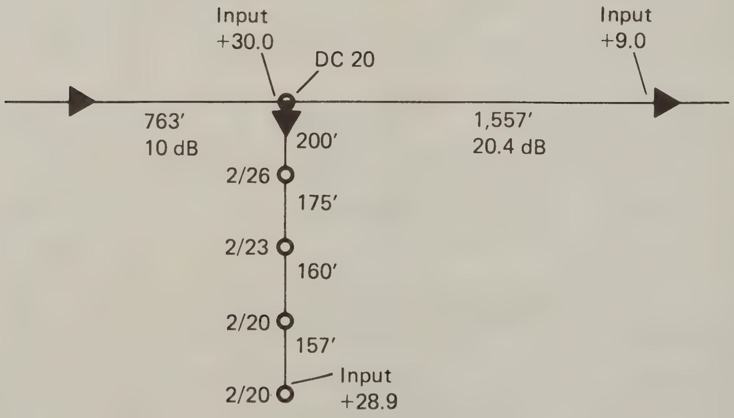

Input
+30.0
DC 20
Input
+9.0
763′
10 dB
200′
1,557′
20.4 dB
2/26
175′
2/23
160′
2/20
157′
Input
+28.9
2/20

Figure 13-13 Directional Coupler with Amplifier

Figure 13-12 shows an 8 dB directional coupler inserted into the main cable route. Note, however, that in order to produce a high enough signal level to completely serve the side lead, we had to connect the high loss output of the directional coupler to the main cable route. This introduces 8 dB of loss into the main cable and significantly reduces the amplifier spacing. This may be an acceptable solution if the system beyond this point (the main cable route) is not very extensive.

If, on the other hand, we had a long extension of the main cable yet to lay out, we might wish to maximize the main cable amplifier spacing. We could accomplish this as shown in Figure 13-13, using a 20 dB directional coupler in the main cable to feed signals directly into a side lead amplifier. This introduces only 0.6 dB of loss into the main cable, and note that the next main cable amplifier is now located 1,557 feet away. Using the previous, passive solution, this location was only 992 feet distant. This may or may not be advantageous enough to accept the cost penalty of the side lead amplifier.

Summary

A brief word on reducing main cable amplifier spacing might be appropriate. The designer should not be unduly timid in close-spacing amplifiers, and we do not mean to overemphasize the penalties. Given a cascade of say 25 amplifiers, the addition of a single unit, due to close-spacing at several points along the route, would have little impact on transmission quality. On the other hand, the economic advantage of eliminating several side lead amplifiers, many of which cannot be efficiently utilized because they serve only a few subscribers, can be quite attractive and should be carefully considered.

Chapter 14

Urban System Design

We will define an urban application as one that requires frequent service tap offs due to the high population density, and further stipulate that the heavy tap loading is distributed evenly throughout the service area. The service area itself is somewhat limited in length and breadth, being most generally confined to town or city limits. The system design technique developed for urban applications, and almost universally employed throughout the CATV industry today, is shown in Figure 14-1.

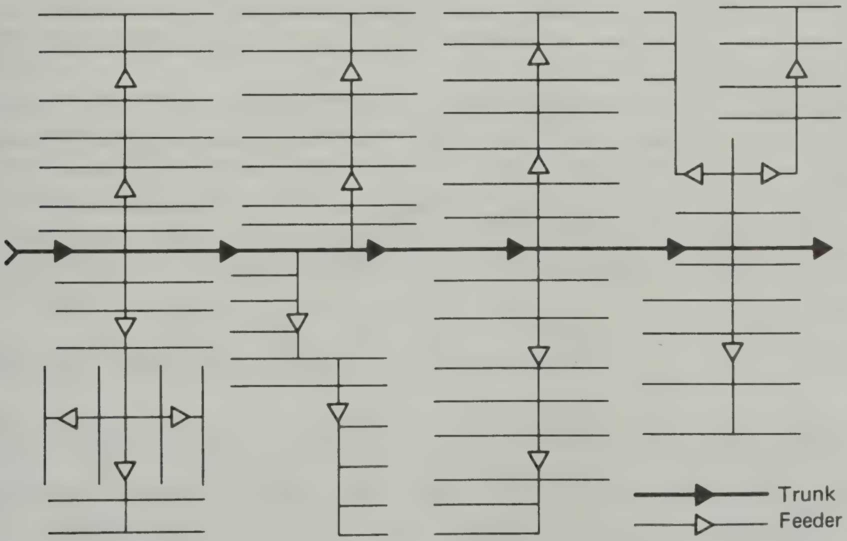


Figure 14-1 Trunk/Feeder Design

General Discussion

The urban designer is faced with evenly distributed, heavy tap loads across the entire service area. In Chapter 12 we discussed tapping efficiency. Given the heavy tap loading of urban applications, it is not surprising that a design philosophy evolved that was directed primarily at maximum efficiency in tapping for service drops. The primary motivation, although not recognized by many in the industry today, for developing the trunk-feeder design was economy in plant construction.

This requires that transmission be maintained at high signal levels, and this in turn imposes higher output levels on system amplifiers. Our earlier studies show that higher output levels contribute higher intermodulation distortion from the amplifiers. If the signals are passed through many high output amplifiers in cascade, this can produce unacceptable end-of-system performance. Of course, maintaining high transmission levels ensures that amplifier input levels will also be higher, and under these conditions we would expect C/N ratios to be quite satisfactory. That is the dilemma posed by the urban requirement; how to limit system distortion while still achieving high efficiency in tapping.

Trunk-Plus-Feeder Philosophy

A practical solution to the problem is to adopt two distinctly different design philosophies and, in effect, design two separate subsystems, combining them to produce an acceptable, overall transmission performance.

If an arterial or backbone transmission system could be devised just to distribute signals generally throughout the service area, this system could be designed for sufficient "reach" to cover the basic area and would also allow some discriminate distribution of noise and distortion contributions.

We might operate this subsystem, which we will call the trunk cable, at conservative, low-amplitude, low-distortion signal levels. This will reduce amplifier spacing, but by using larger-size, lower-loss cables in the trunk system, we can improve the spacing somewhat. Using either shorter spacing, or larger cable sizes in the trunk system, will be more expensive, of course. Since tapping efficiency is not high when system transmission levels are low, we will not utilize the trunk cable for service drop feed at all, and no taps will be cut into the trunk cables. If service tapping is required along trunk cable routes, we must parallel the trunk cable with a second cable to accommodate such taps. This is another cost penalty in the trunk-plus-feeder design philosophy.

The second level subsystem is called "feeder" cable. This is a second level of cable plant constructed to directly serve all service tap loads. It is also an entirely different transmission philosophy. In the feeder subsystem we will intentionally operate with higher transmission levels throughout. This provides a much higher level of efficiency in tapping, as we discussed earlier. As shown in Figure 14-1, the feeder plant is constructed so as to serve the entire area.

We know, from earlier study, that increasing the output levels of amplifiers will substantially increase the intermodulation distortion contributed by each amplifier. In the design of the trunk subsystem, however, we had intentionally sacrificed economy to reduce intermodulation distortion in the trunk plant. Thus, we have reserved some distortion tolerance to permit a higher intermod contribution from the feeder amplifiers.

To limit the feeder intermod contribution to acceptable levels, we will impose a strict limitation on the number of feeder amplifiers we will cascade (connect serially). This limitation may require some additional arterial trunk plant construction to reach some service areas, of course.

Let's examine Figure 14-1 again. This small section of a system might be repeated dozens of times in a larger community. Note that the trunk cable would, in our example, be spaced some distance from the next, paralleling trunk cable. Note also that no feeder cable end is more than two feeder amplifiers away from the trunk cable itself, but actually this is three feeder amplifiers since every feeder cable had to be initiated through the use of a bridger type of amplifier. A bridger amplifier is considered to be a feeder plant unit, but for simplicity, Figure 14-1 does not show bridging amplifiers.

Most generally no automatic gain control (AGC) or automatic slope control (ASC) is provided in feeder amplifiers, for reasons of economy. Thus, these units, called line extenders, are usually quite low in cost. On the other hand, recognizing that no self-regulation is incorporated into the feeder subsystem, it may be desirable to provide a higher level (more frequent) automatic control capability in the trunk plant.

If we used AGC only at every third trunk amplifier, for example, some sections of the feeder plant could be as many as five amplifiers away from regulation (two trunk, one bridger, and two line extender units). This may not be sufficient to ensure end-of-system transmission quality under all temperature extremes. As system channel loading is increased, and 50 and more channel systems are quite common in urban applications, the regulation of system transmission levels becomes more critical. The system tolerance for level variations is reduced, and for this reason, we see more systems providing regulation at every amplifier location in the trunk system today.

We can and do actually address the trunk and feeder designs as separate transmission problems.

Trunk Sub-System

The trunk subsystem in an urban trunk-plus-feeder design might be characterized as using relatively low-gain amplifiers, typically 24 dB or so, operating at rather conservative transmission levels, and often employing larger-size, lower-loss cables. For these reasons, the trunk system is relatively high in cost. Since the trunk plant involves many amplifiers in cascade and operates with relatively low signal levels, the trunk plant is the major contributor of noise in the overall performance of the system.

The low-gain and conservative output levels limit the trunk intermodulation distortion, of course. Thus, at the most distant point on the trunk cable, we would expect to find a C/N ratio at, or very nearly at, the overall system specification. The cross modulation (X-Mod) and other intermodulation products at this point would be significantly better than system specifications require, and consequently the system can accept a relatively large intermod contribution from the feeder plant.

Feeder Sub-System

The feeder plant can be characterized as distinctly and intentionally limited in length and operating at high transmission levels throughout. Thus, the feeder plant will introduce a very nominal amount of noise, but will contribute substantially to system intermodulation distortion. Being limited in length, and not usually equipped with self-regulating equipments, the feeder plant is quite cost-effective. This is also due to the fact that using higher transmission levels permits the feeder cables to be smaller in size and lower in cost although they are higher in transmission loss.

Note that the bridging amplifiers, discussed earlier, are considered an integral part of the feeder subsystem. It is through the use of bridging amplifiers that the transition in transmission levels, from low trunk levels to high feeder levels, is actually accomplished.

Combining Trunk and Feeder Sub-Systems

The overall system performance then, is a function of the trunk and feeder plants operating in tandem. Transmission is through the trunk system to a point where a bridging amplifier introduces higher transmission levels, and then through a limited number of line extender (feeder) amplifiers. The end-of-system performance quality is the combination of both noise and intermodulation distortion contributed by both the trunk and the feeder subsystems.

Extensions of the trunk system are possible to some reasonable extent, particularly if the original design anticipated such subsequent extensions. The extension of a feeder cable leg is distinctly limited, however, since the original design allowed only a specific intermod contribution from any feeder extension. It is possible, during initial system layout, to provide some extension of selected feeder legs, but this requires a reduction in operating levels along the extended feeder to ensure that the X-Mod contribution (from the feeder) does not exceed the original design allotment for feeder contribution.

Both trunk and feeder plant can be bi-directional (two-way) in transmission capability, either initially or by retrofitting plug-in accessories into the amplifiers themselves.

Typical feeder limitations are one bridger amplifier followed by two line extenders. A three-line extender cascade is permitted during initial layout, but all line extender amplifier output levels on that feeder leg must be reduced in such cases.

Thus, in a trunk-plus-feeder system, it is not uncommon to utilize several varieties of amplifiers, and it is inherent in the design to introduce several transmission levels. Consequently, trunk-plus-feeder systems are somewhat more sophisticated to maintain properly.

Equipment varieties might include:

1. Manual trunk amplifiers
2. Automatic regulating trunk amplifiers
3. Bridging amplifiers
4. Intermediate bridging amplifiers
5. Terminating bridging amplifiers
6. Line extender amplifiers

Transmission level varieties might include:

1. Trunk amplifier output levels
2. Bridging amplifier output levels
3. Line extender output levels (2-amplifier cascade)
4. Line extender output levels (3-amplifier cascade)

Generally the use of three line extenders in cascade during system layout is limited to particularly awkward or unusual situations. These might include extensions into limited areas to avoid additional trunk plant construction, or some unique geographic conditions such as rivers, superhighways, etc.

Economics of Trunk/Feeder Designs

If we examine Figure 14-1 again, we will see that there is substantially more feeder cable in this layout than trunk cable. This condition is typical of urban installations. Since feeder plant is significantly less expensive to construct than trunk plant, the trunk/feeder designs can produce a significant advantage in overall system construction cost, and this is the driving force behind the development of such designs.

Let us arbitrarily assign some cost figures to demonstrate this point, but the reader is cautioned that these are only representative for comparison purposes. We will use $7,000 per mile for feeder plant and $10,000 per mile for trunk. If a ratio of four miles of feeder to every one mile of trunk can be produced by the layout process, then a 100 mile system could be analyzed as follows:

20 miles trunk @ $10,000/mi. =	$200,000
80 miles feeder @ $7,000/mi. =	$560,000
Total plant cost (100 mi.)	$760,000
Average cost per mile (100 mi.)	$ 7,600

The economic advantages of trunk/feeder designs are quite compelling, and the techniques of trunk/feeder design have become highly refined. Indeed, the actual design of amplifiers and other system hardware items has been strongly influenced by trunk-plus-feeder economics. However, the effectiveness of the trunk/feeder design is directly related to the characteristics of urban applications.

Trunk Transmission Engineering

If we can establish overall system performance specifications, we can then address the problem of allocating or distributing the acceptable noise and intermodulation distortion between the trunk and feeder subsystems. Let us arbitrarily establish the end-of-system specifications to be 44 dB C/N ratio and -51 dB X-Mod. Now we must establish the operating signal levels for the individual units of equipment in both the trunk and the feeder subsystems.

We must first establish the amplifier cascade that will be required to reach the most distant point on the trunk cable route. This will be an estimate, of course, but if trunk routes have already been selected from the strand maps, the estimate should be sufficiently precise. Note that in establishing the longest trunk route (and the longest trunk amplifier cascade), we must anticipate and provide for any subsequent trunk extensions, not just the trunk plant that will be constructed initially. We must also select the trunk amplifier gain we propose to use, but we can substitute various other gain figures later if we wish, for comparison purposes.

Since the feeder amplifiers will operate with substantially higher input levels and will intentionally be limited in cascade length, we can ignore the feeder C/N ratio entirely and assume that the C/N ratio of the trunk system is effectively the C/N ratio of the total cable plant.

Suppose the trunk amplifier we are considering has a noise figure (NF) of 9 dB and we anticipate a trunk cascade of 22 amplifiers. The input signal level can then be calculated as follows:

$$C/N_{amp} = C/N_{sys} + 10 \log N$$

where C/N_{amp} = C/N ratio for each trunk amplifier in dB

C/N_{sys} = C/N ratio for trunk system in dB

N = number of trunk amplifiers in cascade

Earlier we were given an end-of-system C/N specification of 44 dB. Then to maintain a system C/N ratio of 44 dB through a cascade of 22 units, the C/N ratio required for each individual trunk amplifier can be calculated as follows:

$$C/N_{amp} = C/N_{sys} + 10 \log N$$

$$= 44 + 10 \log 22$$

$$= 44 + 13.4$$

$$C/N_{amp} = 57.4 \text{ dB}$$

Given a 9 dB Noise Figure for each trunk amplifier, the input signal level necessary to maintain a C/N ratio of 57.4 dB may be calculated as follows:

$$Sig_{in} = NF - 59 + C/N_{amp}$$

$$= 9 - 59 + 57.4$$

$$Sig_{in} = +7.4 \text{ dBmV}$$

Given a 22 dB gain amplifier with an input level of +7.5 dBmV, the output level would be +29.5 dBmV. We will assume that the amplifier under consideration has been specified by the manufacturer to produce an X-Mod of -57 dB at an output level of +48.5 dBmV, carrying 30 television channels. If we operate at +29.5 dBmV output, this is 19 dB lower than the amplifier specified output level of +48.5 dBmV. Since X-Mod will improve or degrade 2 dB for every one dB change in output level, a reduction in output of 19 dB will improve the X-Mod (reduce the level of X-Mod) by 38 dB. The specified X-Mod was -57 dB, and improving this figure by 38 dB, the X-Mod from a unit operating at +29.5 dBmV output would be -95 dB.

The system X-Mod from 22 such amplifiers in cascade can be calculated as:

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-95) + 20 \log 22$$

$$XM_{sys} = -68.2 \text{ dB}$$

Then the trunk system transmission performance, through a cascade of 22 trunk amplifiers operating at +7.4 dBmV of input and +29.5 dBmV of output, will be 44 dB C/N ratio and -68.2 dB X-Mod. We are free to manipulate the input or output levels or change the amplifier gain; but before we do so, let us examine the impact of these parameters on the feeder subsystem.

Feeder Transmission Engineering

Since we previously established overall system performance specifications to be 44 dB C/N ratio and -51 dB X-Mod, we can establish the acceptable noise and X-Mod forthe feeder system. The trunk C/N ratio was determined to be 44 dB, so we cannot accept any significant noise contribution from the feeder plant at all.

The trunk X-Mod was determined to be -68.2 dB. From the chart in Chapter 4 (Figure 4-4) we can determine that if the total feeder plant X-Mod were -53 dB, when combined with the trunk X-Mod of -68.2 dB, the overall system X-Mod would be 1.7 dB poorer than the feeder X-Mod. This would be -53 dB less 1.7 dB, for a total X-Mod of -51.3 dB, which would be fully compliant with system performance specifications. We will design the feeder system (select output levels) to produce a -53 dB X-Mod for the feeder plant.

We will assume feeder amplifiers are available with a X-Mod specification of -57 dB at a +52.5-dBmV output level, with 30 channel loading. We will arbitrarily limit all feeder legs to one bridger amplifier followed by no more than two line extender amplifiers, a total feeder cascade of three amplifiers.

If the total feeder X-Mod cannot exceed -53 dB, the allowable X-Mod from each amplifier may be established from:

$$XM_{amp} = XM_{sys} - 20 \log N$$

$$= (-53) + (-20 \log 3)$$

$$XM_{amp} = -62.5 \text{ dB}$$

From the amplifier specifications we know that at +52.5 dBmV of output, the unit produces -57 dB X-Mod. To improve the X-Mod to -62.5 dB, we have to improve it 5.5 dB. Our earlier studies showed us that a 2 dB improvement in X-Mod will result for every 1 dB reduction in output level. Reducing the output by 2.75 dB would then produce a -62.5 dB X-Mod per amplifier. Reducing +52.5 dBmV of output by 2.75 dB will leave a +49.75 dBmV output. We can round this off to +50 dBmV, the operating output level for all feeder amplifiers.

The input level to the line extenders will be a function of the gain of the units selected. For example, if these units have 28 dB of gain, this is fairly representative, and the output level is +50 dBmV, then the input levels will be at least +22 dBmV. It is readily apparent that amplifiers operating with such high input signals will produce an excellent C/N ratio. We can effectively ignore the noise contribution of the feeder amplifiers for this reason, and because there will be only three of them in cascade.

Before we summarize our results, let us consider the impact on feeder performance if we add one more line extender operating at the +50 dBmV output level.

Extending the Feeder Cascade

If we add a line extender amplifier we now have a cascade of four units, each producing -62.5 dB X-Mod. Under these conditions the total X-Mod from the feeder system would be established from:

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-62.5) + (20 \log 4)$$

$$XM_{sys} = -50.5 \text{ dB}$$

This performance by itself is out of specification for the system, and if we combine this figure with the trunk X-Mod (-68.2 dB), the overall X-Mod would be even lower (at -49.5 dB). You will recall that system requirement was established to be -51 dB X-Mod.

Whenever we violate the rule of three feeder amplifiers in cascade (one bridger plus two line extenders) we will have to reduce the output level of all the line extenders by 3 dB in order not to compromise the X-Mod performance at the end of the extended feeder leg. Note that we cannot, indiscriminately, add a line extender to any in-place, operating feeder leg without rather extensive rearrangement of amplifier spacing and possible change out of some subscriber tap units also.

Summarizing the Trunk/Feeder Engineering

The end result of our engineering effort established the following:

Trunk Amplifiers

Input signal level	+7.5 dBmV
Output signal level	+29.5 dBmV
C/N ratio (per amplifier)	57.5 dB
X-Mod (per amplifier)	-95.0 dB

Feeder Amplifiers

Input signal level	+22.0 dBmV
Output signal level	+50.0 dBmV
C/N ratio (per amplifier)	not significant
X-Mod (per amplifier)	-62.5 dB

The cascade of 22 trunk amplifiers would produce end-of-trunk performance as follows:

$$C/N_{trk} = C/N_{amp} - 10 \log N$$

$$= 57.5 - 10 \log 22$$

$$= 44.0 \text{ dB}$$

$$XM_{trk} = XM_{amp} + 20 \log N$$

$$= (-95.0) + (20 \log 22)$$

$$= -68.2 \text{ dB}$$

The cascade of three feeder amplifiers would produce end-of-feeder performance as follows:

C/N_{fdr} is not significant due to high input levels.

$$XM_{fdr} = XM_{amp} + 20 \log N$$

$$= (-62.5) + (20 \log 3)$$

$$= -53.0 \text{ dB}$$

The combination of trunk X-Mod (-68.2 dB) and feeder X-Mod (-53.0 dB) is -51.6 dB, fully compliant with system specifications. The trunk C/N ratio may be taken to be the system C/N ratio, and is 44 dB, also fully compliant.

Although we have done this using only 30 channel loading and X-Mod as the disturbing intermodulation distortion, the process would be the same for say 50 channel loading and Composite Triple Beat distortion, only the figures would change. Interested readers are encouraged to duplicate these calculations using different trunk amplifier gain and different operating levels to reinforce their understanding of the trunk/feeder relationship in regard to overall system transmission performance.

Summary

Although the trunk/feeder design is almost universally applied in the CATV industry to all situations, it by no means follows automatically that it will always be optimally cost-effective. As we have seen, several conditions must exist for the trunk-feeder design to be attractive. These are:

1. There must be high tap loading requirements.
2. The situation should provide a high ratio of feeder to trunk plant.
3. There must be a significant cost differential between trunk and feeder plant, both in cable costs and in amplifiers.

Chapter 15

Rural System Design

We will define a rural application as one that requires relatively infrequent service tap offs, due to a low population density, and we further stipulate that the tap loading is thinly distributed and random throughout the entire service area. However, the service area itself is quite extensive in length and breadth, and we may anticipate system extensions on the order of 15 miles or more.

Most rural situations will include some small town or hamlet that we will refer to as the core community. Within this limited core area, the tap load will be somewhat higher in density and some special design approach here may be advantageous. If this area were sufficiently dense or large, we might even find the urban trunk/feeder design attractive, which is very improbable in most rural applications. For purposes of this discussion, we will ignore the core community for the moment and address the "out-of-town" applications only, but in the next chapter we will discuss small town and core community applications in some depth. This subsequent discussion will be more meaningful if we first understand the rural system design philosophy.

General Discussion

In the majority of rural applications, the probability of developing advantageous trunk-to-feeder ratios is very remote indeed. Since system extensions will be quite long (15 miles or so) and tap loading relatively light, the trunk/feeder design will not be cost-effective. We would find very long extensions of trunk, almost entirely paralleled with feeder, and at the end of the trunk plant, no "clusters" or groups of subscriber service points. Feeder cable that simply parallels trunk to accommodate tapping is not cost-effective construction.

The "in-town" segments of rural systems are not a great deal more promising. Studies show that most rural systems will require only 15 miles or so of "in-town" plant combined with perhaps 100 miles or more of rural construction.

Even if subscriber densities in town favor a trunk/feeder design approach, the overall ratio would present a marginal cost advantage at best. This might be easily offset by the logistical disadvantage of introducing several different types of equipment, particularly when only a few units of some types might be employed. Consider a rural system employing perhaps 250 amplifiers in 100 miles of plant but utilizing only three or four bridging amplifiers and perhaps 10 or 15 line extenders.

The major challenge of rural and all smaller CATV operations is the limited base of potential revenue. We are required to construct a substantial amount of plant that will pass only a limited number of potential subscribers. Not only must we aggressively address system construction costs, we cannot afford a high level of sophistication in maintenance personnel or in test techniques and equipment either.

Perhaps the most cost-effective approach would be a single coaxial cable utilized both for signal distribution, as the urban trunk cable was employed, and accommodating all service taps as the urban feeder system does. If we distribute the allowable noise and distortion contribution across only one level of design, we might operate this plant at somewhat higher distortion levels than the urban trunk but at somewhat lower distortion levels than the urban feeder.

A major cost reduction would be eliminating a lot of parallel cable costs; but we might also space our amplifiers farther apart and using fewer units than in an urban trunk system. Before we investigate such a radical departure from the conventional trunk/feeder philosophy, let us first consider simply adapting either trunk design alone or feeder design alone to a rural application.

Applying Urban Trunk in Rural Designs

If we simply attempt to "lift" the urban trunk system design and apply it to rural situations on the apparently reasonable assumption that it has been highly refined and proven effective in so many existing operating systems, a closer examination quickly points out the fallacy of such reasoning. In a trunk/feeder system, the trunk subsystem was intentionally designed to operate with reduced output levels in order to allow a high distortion contribution from the subsequent feeder sub-system. The overall system performance was the result of transmission through both the trunk and feeder plant in tandem. This approach produced high efficiency in tapping throughout the feeder plant but low cost-efficiency in the trunk plant, which was quite expensive to construct.

In reference to transmission, if we examine a long cascade of trunk amplifiers, say 25 units or so, we would find that at the end of this cascade the noise level was at or nearly at the overall system C/N ratio specification. However, the X-Mod would be quite a bit better than system specifications required. In the trunk/feeder system it was intended to extend beyond, or off, the trunk plant into high-level, high-distortion feeder to accommodate dense tapping loads.

In the rural application no such substantial tap loading is encountered. At the ends of a rural cable route we will find only a single or very few subscribers.

The urban trunk plant, if extended out to this point, would become noise limited well before it even approached the specified intermod distortion limits.By using higher-gain amplifiers and higher output levels, we could increase the amplifier spacing and decrease the plant costs. This would increase the intermodulation distortion contribution from each amplifier, but using the conventional trunk design alone, X-Mod was quite a bit better than the specifications required anyway. In effect, we might increase amplifier gain and spacing by redistributing the total allowable system distortion along the entire rural system rather than reserving some distortion for feeder extensions that offer no advantage to construct.

In this rural system design concept, if we do not change the amplifier input levels we would not change the system C/N ratio at all; and noise wise, the end-of-system performance at the worst-case, most distant subscriber location would be identical with the trunk/feeder design performance. If the increased X-Mod due to the higher output levels is carefully approached, the overall X-Mod performance of the system could also be the same as with the trunk/feeder design.

Now the same cascade of amplifiers, 25 or so, would be spaced farther apart and the overall "reach" or length of the cable route would be significantly greater. This extended coverage imposed no cost penalty since the same number of amplifiers were involved in each case.

Applying Urban Feeder to Rural Requirements

The possibility of applying urban design feeder plant techniques in rural locations simply will not work at all if we are trying to maximize system reach. In the preceding chapter we found that even three line extenders operating at a +50 dBmV output level would violate system performance specifications. It is obvious that we cannot cascade any significant number of amplifiers at all without severely reducing the output levels, and thus the intermod distortion.

It would be incorrect to assume that trunk/feeder design techniques do not make good sense. They certainly do and will probably continue to do so, but only in high-density urban applications. In a totally different situation, and the rural requirement presents a completely different set of conditions, the urban approach will not be cost-effective and may well introduce significant cost penalties.

What appears worthy of consideration is a hybrid or composite design that combines features of both trunk and feeder techniques. This will be more economically practical for rural applications. Before we discuss such a design let's examine system specifications for the rural situation.

Rural System Specifications

In view of the marginal economics of smaller and rural CATV operations, we cannot ignore any possible reductions in cost of design or in long-term system operation. As the rural system extends out farther, the problem becomes more severe.

The number of subscribers to be served in that area becomes smaller. The quality of transmission is poorest at the extremities of the system, of course. Since the most distant sections of the rural system serve only a very small percentage of the total subscribers, we might consider relaxing the end-of-system specifications somewhat.

Several studies conducted by the author suggest that performance specifications for rural systems might be relaxed to 40 dB C/N ratio and -50 dB X-Mod without seriously affecting the salability of the service or the economic viability of the operations. The impact of such an action on overall system cost should certainly be thoroughly examined by anyone seriously investigating a rural CATV application, but this does not constitute an endorsement of relaxing specifications. We are trying to understand the technology, and the technical possibility does exist and ought to be mentioned.

Single Cable Design Technique

We need an appropriate terminology for the rural design technique. In the earliest days of CATV development the technique of tapping a single cable throughout the system was fairly common. It was abandoned largely due to the technical shortcomings of the type of subscriber taps in use at that time and because, as systems were constructed in larger and larger communities, the trunk/feeder concept was found to be more cost-effective.

In the early days of the industry the single cable approach was called "tapped trunk," but this is a misnomer for our rural design. As we have discussed, the concept is not to utilize the basic trunk operating levels at all but to shift output levels closer to feeder amplifier operations and use higher amplifier gain. The terminology "tapped trunk" would inevitably introduce confusion, particularly if some applications might usefully employ both techniques (rural design and trunk/feeder) in different portions of the same system.

Technically the term "distributed distortion" might be reasonably descriptive but this seems somewhat cumbersome. We have heard the term "feeder-less design" suggested, but it introduces connotations from the more conventional trunk/feeder-nomenclature also.

For lack of a better definition, we have come to use the term "single-cable design." This is somewhat less than completely satisfactory since we may sometimes actually parallel the primary cable with short sections of a second cable for the purpose of isolating taps but in such instances we will not transition to different transmission levels in the secondary cable. Using "single-cable" terminology, let us compare all three design techniques; trunk, feeder, and single cable.

Technical Comparison of Techniques

We will assume end-of-system performance specifications are the same for all three designs, that is, 44 dB C/N ratio and -51 dB X-Mod distortion.

For clarity, we will not include any service taps at all or any splitters or directional couplers. Amplifier performance with 30-channel loading for the three design techniques is taken to be as follows:

	Trunk	Feeder	Single Cable
Input signal level	+7.5 dBmV	+22.0 dBmV	+8.0 dBmV
Output signal level	+29.5 dBmV	+50.0 dBmV	+40.0 dBmV
Usable gain (spacing)	22.0 dB	28.0 dB	32.0 dB
C/N ratio (per amp.)	57.5 dB	N/A *	59.0 dB
X-Mod (per amplifier)	-95.0 dB	-62.5 dB	-82.0 dB

* Feeder C/N is not significant due to high input level.

A cascade of 22 trunk amplifiers would produce a C/N ratio of 44 dB from

$$C/N_{sys} = C/N_{amp} - 10 \log N$$

$$= 57.5 - 10 \log 22$$

$$= 44 \text{ dB}$$

A cascade of 22 trunk amplifiers would produce X-Mod at -68.2 dB from

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-95) + (20 \log 22)$$

$$= -68.2 \text{ dB}$$

A cascade of four feeder amplifiers would produce X-Mod at -50.5 dB from

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-62.5) + (20 \log 4)$$

$$= -50.5 \text{ dB}$$

The high feeder amplifier input levels make a C/N calculation academic.

A cascade of 33 single cable amplifiers would a C/N ratio of 44 dB from

$$C/N_{sys} = C/N_{amp} - 10 \log N$$

$$= 59 - 10 \log 33$$

$$= 44 \text{ dB}$$

A cascade of 33 single cable amplifiers would produce X-Mod at -51.6 dB from

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-82) + (20 \log 33)$$

$$= -51.6 \text{ dB}$$

We can tabulate the comparison results as follows, assuming 1.31 dB cable loss per 100 feet of cable for all three cases:

	Trunk	Feeder	Single Cable
Amplifier cascade	22	4	33
Usable amplifier gain	22 dB	28 dB	32 dB
Amplifier spacing	1,679 ft	2,137 ft	2,442 ft
System length	7.0 miles	1.6 miles	15.3 miles
System C/N ratio	44 dB	N/A *	44 dB
System X-Mod	-68.2 dB	-50.5 dB	-51.6 dB

* Feeder C/N ratio is not significant due to high input levels.

Note that all three designs are fully compliant with the system specifications, but the single-cable design produced the longest "reach" (15.3 miles). Quite obviously, when we apply this design in an actual system we will not achieve this distance. The insertion of subscriber taps, directional couplers, and splitters will shrink the amplifier spacing and consequently reduce the overall system length. This is equally true of either of the other two concepts, of course.

We could actually improve the single-cable design slightly since it exceeds the X-Mod specification by 0.6 dB; only -51 dB X-Mod was required. This would allow slightly higher input and output levels but the cascade improvement would not be substantial.

Impact of Relaxing System Specifications

We discussed the possibility of relaxing the specifications in rural applications.

If we accepted a 40 dB C/N ratio and -50 dB of X-Mod at the end of a rural system, the same single-cable amplifier we just used in the comparison could produce a cascade of 40 units. At this point, the end-of-system C/N ratio would be 42.9 dB and the X-Mod -50 dB. By shifting the operating levels down 0.5 dB we could increase the cascade to 45 amplifiers and still be completely compliant with system specifications. A cascade of 45 units would be a system 20.8 miles long if no insertion loss for taps, splitters, etc., is considered. Even if we include such devices the system length would be on the order of 18 miles or so, depending upon the inserted device losses.

Parallel Cable Placement

The single-cable design may still require some limited placement of parallel cable along portions of the system. Some of this placement will be dictated by the low input levels at the amplifiers, which may require "back-feed" cable placement as discussed earlier in the text. When the length of the rural system and the service tap distribution along that length is excessive, it may be prudent to "shed" or off-load some of the taps.

In the central or core community in rural systems, an alternative single-cable design may be more cost-effective. This application may require some parallel cable placement on the long extension cable routes that pass through the town to "shed" the tap loading on those cables, thus preserving tap load capability for the out-of-town portions of the system. The nomenclature "single-cable" design should not be taken to prohibit any use of parallel cable at all. When a significant technical or economic advantage can be attained, a second cable can and should be placed, but such placement is an engineering judgment and is neither prohibited nor mandatory under the design philosophy.

Limitations of Single-Cable Designs

There is nothing inherent in the single-cable concept that restricts the transmission capacity of the system. If higher transmission frequencies are required to expand the transmission bandwidth, transmission losses will be greater both for the cable itself and for all passive devices employed, but all of these penalties of expanding transmission bandwidth are equally applicable for trunk/feeder designs. No unique technical limitation on transmission capacity is incurred by the single-cable design itself. Note that smaller rural systems will usually not require substantial bandwidth since the subscriber base is small and the supportive revenue will be somewhat limited also. Most rural type systems will be economically limited to 300 MHz or so, in the author's opinion.

Greater bandwidth implies more signals carried, and as our earlier studies showed, more signals carried means higher intermodulation distortion. Thus a rural system presenting more bandwidth for use will require closer spaced amplifiers and will be more expensive to construct.

Self-Regulation in Single-Cable Systems

The higher operating output levels in the single-cable design can be utilized in several different ways.

1. They improve tapping efficiency and, to some extent, reduce the insertion loss of the taps, limiting the penalty of tapping on amplifier spacing.

2. They allow the use of smaller-size, lower-cost cable even though the transmission loss of such cable is higher.

3. If a larger-size, lower-loss cable is used, amplifier spacing can be substantially increased. However, this will or may also increase the required length of back-feed cable runs.

As a general rule, the higher gain will mean somewhat longer amplifier spacing in every case. Given longer cable sections, the level variations due to thermal changes will be greater, and in single-cable systems AGC or ASC may be required more frequently than it was in the conventional, short-spaced, urban trunk plant.

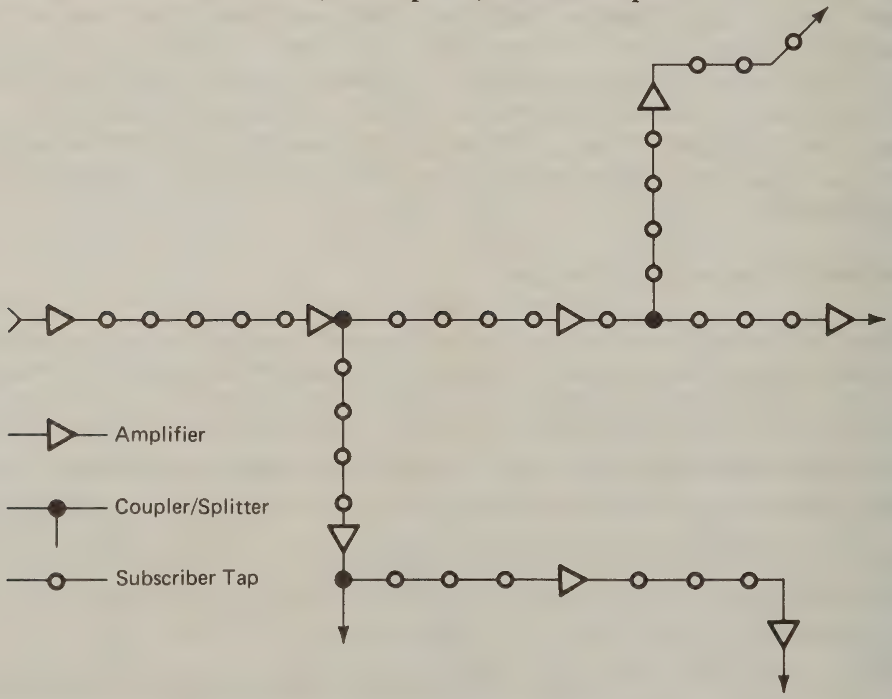


Figure 15-1 Single Cable Design

The provision of automatic self-regulation at every station may have real merit in reducing the sophistication of long-term system maintenance, however. In Figure 15-1 we show a small section of a single-cable system. If each amplifier in the system, wherever it may be located, was identical with every other amplifier, and if all amplifiers were operating with identical input and output levels, then all amplifiers would be, for all practical purposes, directly interchangeable.

A single amplifier, set up on a test bench to have the same input and output levels as those used throughout the system and adjusted for the same "tilt" across the output, could serve as a maintenance replacement spare for all "in-service" amplifiers. In practice, service restoration, due to amplifier failure for example, could be effected by simply plugging in this maintenance spare with no subsequent amplifier adjustment in the field. Some test equipment or indicating device would be necessary to isolate which unit in the system was inoperative but this device could be very inexpensive in that no precise, quantitative measurements are required. All that is necessary is to locate the point where all signals are absent, requiring only a relatively low level of test sophistication.

Perhaps equally important, the level of sophistication or experience in personnel necessary to restore service would be reduced. In small CATV systems the revenue base cannot support highly trained people. If lower levels of experience can be used, with a high level of confidence that end-of-system transmission quality is not compromised, the long-term benefits could be very significant. This approach to system maintenance is discussed in greater depth later in the text.

This approach would be substantially enhanced by the provision of self-regulation (AGC and ASC) at every equipment location. The additional equipment expense may be quite acceptable if, in fact, some reduced maintenance cost is produced, since such a cost advantage would be derived across years of system operation.

Given the variety of equipments and several distinctly different transmission levels in a trunk/feeder system, the simplified maintenance program will be more difficult to implement and perhaps somewhat less effective in urban systems. The urban revenue base can adequately support a more sophisticated approach, however.

Transmission Engineering a Single-Cable System

Following the development of a single-cable design will develop a better understanding of the design concept, and even if the reader is employed in a more complex urban installation, understanding the adaptation of the technology in this manner may reinforce the readers general comprehension of coaxial cable transmission. In the absence of real data we will arbitrarily define the requirements for a 220 MHz application to be:

System Specifications

End-of-system C/N ratio	40 dB
End-of-system X-Mod	-50 dB

Amplifier Specifications

Operating input level	+8 dBmV
Operating output level	+40 dBmV
C/N ratio (at +8 dBmV input)	59 dB
X-Mod (21 Chans. at +40 dBmV)	-82 dB

System Characteristics

Highest transmission frequency	220 MHz
Channel loading	21
Tap density (2-port taps)	5 per mile
System length	15 miles

We cannot determine actual tap values since precise tap locations are not known and no strand or pole line map is available. We will conservatively assume 1.4 dB will be the average insertion loss per tap, and further assume that 2.5 taps will be inserted into each cable section throughout the entire system. Tap insertion loss between all amplifiers is taken to be a total of 3.5 dB from 2.5 x 1.4 = 3.5. This can be shown to represent loading of more than five taps per mile.

We cannot establish how frequently directional couplers or splitters must be inserted since no maps are available. We will assume that coupler/splitter losses would average out to 1.5 dB per cable section along the entire length of the system, again a very conservative approach. Although the transmission design is for an operating output level of +40 dBmV, we will reserve 1 dB for future tap loading as discussed earlier in the text.

Using .500 inch foam dielectric cable throughout, at 220 MHz, cable loss is taken to be 1.09 dB per 100 feet and non-cable transmission losses consist of:

Tap losses	3.5 dB
Coupler/splitter losses	1.5 dB
Reserve gain	1.0 dB
Total non-cable losses	6.0 dB

Given +8 dBmV of input and +40 dBmV of output, amplifier spacing would be 32 dB. Subtracting 6.0 for all non-cable losses we can accommodate 26 dB of cable in each cable section. At 1.09 dB loss per 100 feet, 26 dB of cable would space amplifiers 2,385 feet apart. Then 33.2 amplifiers will be required to extend the system 15 miles, but we will round this off to 34 amplifiers.

The end-of-system C/N ratio for a cascade of 34 amplifiers may be established by the following equation:

$$C/N_{sys} = C/N_{amp} - 10 \log N$$

$$= 59 - 10 \log 34$$

$$= 43.7 \text{ dB}$$

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-82) + (20 \log 34)$$

$$= -51.4 \text{ dB}$$

This performance is better than system specifications call for. We might, by manipulating the operating signal levels, actually extend the system somewhat and still be fully compliant. Reducing the input 1 dB to +7 dBmV will reduce the output 1 dB to +39 dBmV. This will degrade single amplifier C/N from 59 to 58 dB but will improve X-Mod from -82 to -84 dB. The system can now be extended to 45 amplifiers in cascade (20 miles) and will perform as follows:

$$C/N_{sys} = C/N_{amp} - 10 \log N$$

$$= 58 - 10 \log 45$$

$$= 41.5 \text{ dB}$$

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-84) + (20 \log 45)$$

$$= -50.9 \text{ dB}$$

Both parameters are better than the system specifications require, and note that the entire system utilized low-cost .500 inch cable throughout. Let us examine the impact of a higher transmission frequency limit.

300 MHz Single-Cable System

In a 300 MHz single-cable system we will assume that the end-of-system specifications remain the same, but with the additional channel loading (from 21 to 35 channels), amplifier X-Mod will be quite a bit higher. We can simply degrade the amplifier X-Mod figure and recalculate system performance maintaining the +40 dBmV output level as before, or we can derate the output level 3 dB and maintain the same X-Mod performance as before (-82 dB).

Or we might utilize a larger size, lower loss cable. Let's simply derate the output to +37 dBmV from the earlier +40 dBmV.

At the higher frequency, cable loss and tap losses will also increase. We will assume all non-cable losses went up to a total of 7.0 dB from the previous 6.0 dB. Then from a usable gain (spacing) of 29 dB (from +8 in, +37 out) we have amplifier spacing of 22 dB. Using 1.31 dB per 100 feet for cable loss at 300 MHz (.500 inch cable), the physical spacing between amplifiers reduces from 2,385 to 1,679 feet.

To extend the system 15 miles now requires 47.2 amplifiers which we will round out to 48 units. If we maintain the +8 dBmV of input and use a +37 dBmV output, the performance through 48 units would be as follows:

$$\begin{aligned} C/N_{sys} &= C/N_{amp} - 10 \log N \\ &= 59 - 10 \log 48 \\ &= 42.1 \text{ dB} \\ XM_{sys} &= XM_{amp} + 20 \log N \\ &= (-82) + (20 \log 48) \\ &= -48.4 \text{ dB} \end{aligned}$$

Note that X-Mod is now out of specification since -50 dB was required. If we reduce operating levels 1 dB as we did earlier, performance through 48 amplifiers would be calculated as follows:

$$\begin{aligned} C/N_{sys} &= C/N_{amp} - 10 \log N \\ &= 58 - 10 \log 48 \\ &= 41.2 \text{ dB} \\ XM_{sys} &= XM_{amp} + 20 \log N \\ &= (-84) + (20 \log 48) \\ &= -50.4 \text{ dB} \end{aligned}$$

We are now fully compliant but we cannot extend the system beyond 15 miles without some remedial action. We might reduce tap insertion losses by judiciously "shedding" some of the tap load onto a second, paralleling cable.

Or we might utilize a larger-size, lower-loss cable for part of the system, reducing the amplifier cascade somewhat.

Note that given the same tap loading and coupler/splitter losses and using the same size cable (.500 inch), the higher frequency required a 48 amplifier cascade and the lower frequency only 45 units, but both designs were fully compliant with system specifications.

The insertion losses applied in these developments were by no means benign; if anything, they were excessively stringent, and the results of the comparison should not be accepted as absolute. We selected the figures for a dramatic contrast or change. In several studies conducted but not presented here for brevity, a change from 21 channel capacity to 35 channel capacity imposed a 15 percent to 18 percent cost penalty on construction costs.

Potential Problems in Single-Cable Systems

Engineering has been called the art of compromise, and if the single-cable design offers economic inducements, it also presents some potential problems. Since many devices, including amplifiers, taps, couplers, and splitters, will be inserted into a single coaxial cable, the mechanical reliability of a large number of cable connectors must be considered. Experience indicates that after an initial period of "de-bugging," most coaxial cable plant will be acceptably reliable and mechanical considerations should not be a limiting factor. Perhaps the single-cable technique of construction does place heavier emphasis on workmanship, but one cannot argue that a lower quality of workmanship would be acceptable in conventional system construction.

There are some unique aspects of single-cable construction that could be improved by different equipment configurations, however. Analysis of several single-cable designs shows that a high percentage of amplifier installations will require a passive device or two at the amplifier output. These might be directional couplers to accommodate backfeed cable, taps where the amplifier has been close spaced, or splitters to establish divergent side lead cable routes. In all cases this can be accomplished by using external, off-the-shelf units, but some flexibility for output connections built into the amplifier housing itself could be useful. In an earlier chapter we showed signal director capability establishing feeder cable points in bridging amplifier stations. A less expensive, less sophisticated adaptation of the "feeder maker" technique would be very convenient in single-cable amplifier equipments.

In Figure 15-2 we show a conventional, two-port housing including a forward and return amplifier module. This would be typical of a single-cable amplifier. Figure 15-3 shows a four-port housing with the housing base plate equipped for signal director capability.

Figure 15-4 shows various applications utilizing the signal director. Note that in underground plant where amplifiers are vertically mounted in pedestals, the use of shorting straps in the signal director would permit both input and output cables to enter the amplifier housing at the same end.

In splitter or coupler applications, all signal division is accomplished through plug-in, board-mounted circuitry which, since it is connected "inside" the amplifier 60 Hz AC bypass circuitry (which is not shown in the figures for clarity), need not address power-passing requirements at all. The signal director capability in a long cascade of amplifiers would significantly reduce the number of cable connectors involved in a single-cable system.

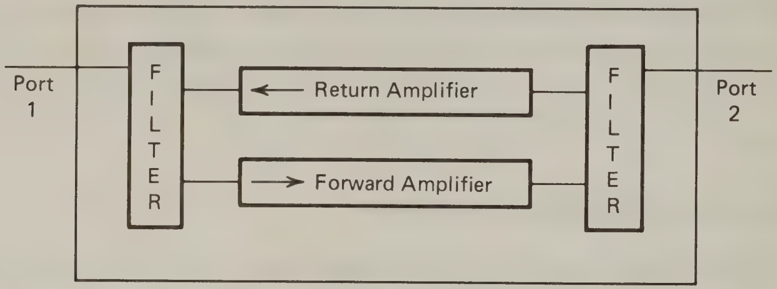

Port 1
FILTER
Return Amplifier
Forward Amplifier
FILTER
Port 2

Figure 15-2 Two-port Housing

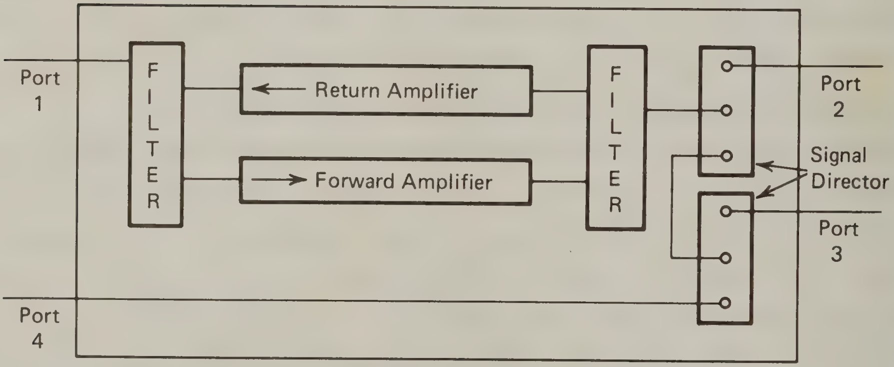

Port 1
FILTER
Return Amplifier
Forward Amplifier
FILTER
Port 2
Signal Director
Port 3
Port 4

Figure 15-3 Four-port Housing

It can be argued that a proliferation of automatic control equipment (at every station perhaps) will lead to random instability in signal levels (AGC "hunting") at the end of long cascades. The visible effect on television screens can be continuous "breathing" or "blooming" in the picture. This phenomenon, sometimes called intensity modulation, was common in the early development days of CATV and was the result of short period time constants in AGC circuits. Tests conducted in the field on modern-day equipments using longer AGC time constants show no instability at all, even when the introduced signal level variations were very rapid and extreme.

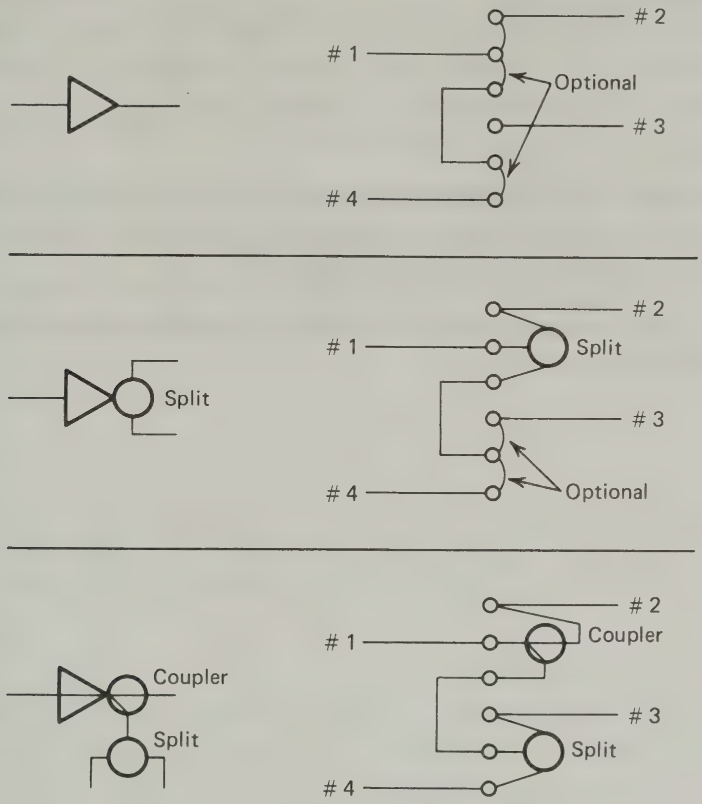


Figure 15-4 Signal Director Applications

extreme in amplitude. The cascade of many amplifiers required in rural applications raises the question of reliability of the amplifiers themselves. The author's personal experience indicates that modern equipment is quite satisfactory in this respect. In any event, the cascade cannot be eliminated by trunk/feeder design techniques and could very well be increased due to the lower-gain, closer-spacing characteristics of trunk plant.

Summary

There are no compelling, technical disqualifications for the single-cable design technique. Several studies have shown the single-cable design to be consistently less expensive in rural applications, with cost savings on the order of 25 percent to 35 percent.

Although the study of single-cable designs may appear to be irrelevant for readers working in urban environments, it certainly will expand the readers understanding of the general technology to consider how it might be applied differently in different situations. The reader is encouraged to review this chapter for this reason.

The single-cable system is an excellent candidate for high-density self-regulation, perhaps even AGC at every station.

When auto-control is installed more frequently in a system, the corrective range of the units employed should, ideally, be reduced. If corrrective spacings are only 2 dB across anticipated temperature variations, then units that have a 4 dB corrective capability are not necessary, and in the unlikely but possible event of a loss of regulating carrier, this excessive range will almost certainly impose out-of-specification performance at the end of the system.

Chapter 16

Modified System Designs

Some special service applications may be best served by modifications of the two basic design techniques, trunk-feeder and single-cable, or by a combination of both techniques utilized in different sections of the same system.

Super-Trunk

The term super-trunk might be defined as a transportation system rather than a distribution system. By that we mean the transportation of signals between two discrete points rather than the distribution of signals to many points, such as many subscriber residences. Figure 16-1 shows a primary signal origination point interconnected to four secondary distribution centers designated as "hubs." Each of these hubs represents an individual local distribution system and may in itself include trunk and feeder plant or it may have been designed as a single-cable system. Each of these distribution systems may or may not be bi-directional.

In a super-trunk application, the signal flow from the primary origination point to each hub is through coaxial cable facilities. Although all four super-trunks shown in the figure may be carrying the same signals, for transmission engineering purposes each super-trunk is a separate application to be addressed. Calculating transmission performance to the end of a system extremity in cable system A, for example, will involve the noise and intermodulation distortion contributions from the super-trunk feeding Hub A, and the noise and intermod contributed by the system A distribution plant itself. The super-trunk itself may or may not be bi-directional.

Since the signals transported to the hub locations will then be applied to the local distribution plant and will accrue all the noise and distortion that this plant contributes, the amount of noise and distortion we can accept from the super-trunk itself is distinctly limited. Thus, the super-trunk design must be quite conservative, particularly if the super-trunk is very long and involves a large number of amplifiers.

Transmission levels must be carefully selected. Often a larger size, lower loss cable is employed to reduce the number of amplifiers required, even though the cable cost is increased. The severe requirements for high quality transmission makes super-trunk plant somewhat expensive to construct.

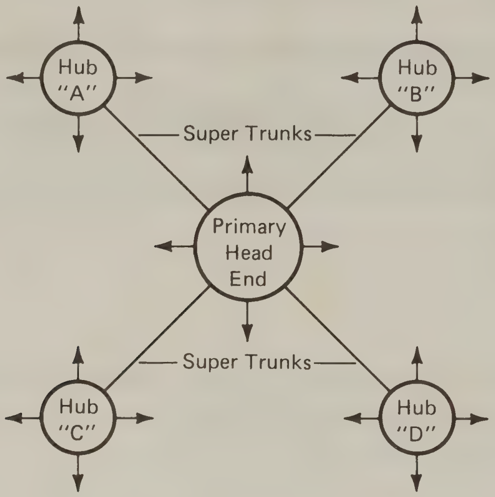

Hub "A"
Hub "B"
Super Trunks
Primary Head End
Super Trunks
Hub "C"
Hub "D"

Figure 16-1 Super-trunk

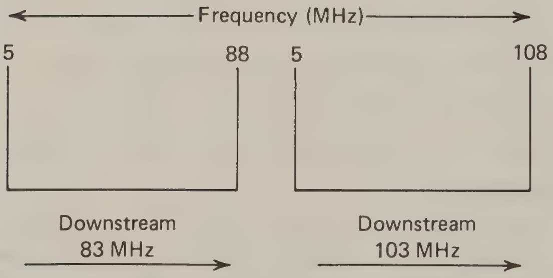

Frequency (MHz)
5
88
5
108
Downstream 83 MHz
Downstream 103 MHz

Figure 16-2 Super-trunk Frequency Allocations

There are some practical techniques to reduce the noise and intermod contribution. If the number of signals that must be transported is limited, we could reduce the transmission bandwidth required and limit the high frequency requirement. We might also carry some of the signals at either sub-band or low-band frequencies only. We could supply transmission between 5 and 88 MHz, which could accommodate 13 television signals, or perhaps 5 to 108 MHz that could handle 17 signals. Either of these would limit the upper transmission frequency requirements, reducing interconnecting cable losses and thus reducing the number of amplifiers required in cascade.

Another possible technique would employ frequency modulation (FM) for all signals carried on the super-trunk rather than amplitude modulation (AM). Using FM will not actually improve the system C/N ratio, but FM signals are less vulnerable to noise. This approach will require demodulation from vestigial sideband AM to video and audio, re-modulation to FM, and reconversion at each hub also, since the end devices served are subscriber television receivers and these require an AM input. The use of FM in the transportation system will also require greater system bandwidth, since an AM television signal occupies 6 MHz but an FM signal occupies 13 or 14 MHz.

Super-trunk plant is rarely tapped for subscriber service, and obviously one reason is to relieve the plant of tap insertion losses. Keep in mind that the use ofsub-channel frequencies for super-trunk transportation also makes it unsuitable for subscriber service since the subscriber receivers do not normally tune such frequencies.

To reduce the number of signals that must be transported over the super-trunk, it is desirable to acquire as many signals right at each hub location, insofar as this is possible. Thus strong local off-air signals are sometimes picked up at each hub location and simply added to the super-trunk delivered signals for application into the local distribution system. This technique offers the advantage that if the super-trunk plant is disrupted due to equipment failure or any other cause, the local plant subscribers will still receive some television signals, at least.

With the development of microwave equipment and more recently lightwave transmission systems, coaxial super-trunk is less frequently employed. We will discuss the alternative transportation of signals using these other technologies later in the text.

Institutional Cable

A relatively recent development in cable television is the introduction of what are sometimes referred to as "institutional cables." These are separate coaxial cables that parallel the regular CATV cables through part if not all of the service area. Although the institutional cables are usually placed concurrent with the CATV cables, they represent an independent and entirely separate transmission system. Usually the institutional system will be bi-directional, and in Figure 16-3 we show a typical spectrum allocation for a 300 MHz system.

The intent is to provide transmission facilities for data, voice, or video signals that are not a part of the CATV operation at all, and to lease this capability to commercial or other potential users along the cable route. Some examples of usage of this separate plant might be the interconnection of all schools within the service area, or interconnecting several municipal properties. Most generally the information carried on institutional cables is not distributed for public viewing or access on the CATV system itself, although such usage is technically possible.

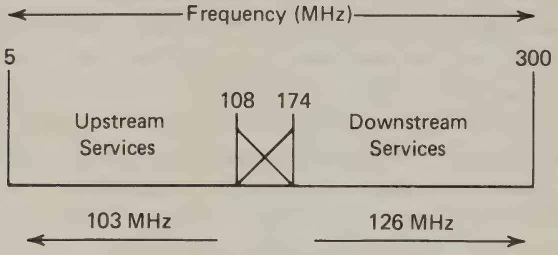


Figure 16-3 Institutional Cable

The design and construction of institutional plant is necessarily somewhat customized for each application, but it does not typically involve a large number of service points or drop connections. Transmission specifications depend to some extent on whether the private user signals must be extended through connections to other transmission systems, perhaps the public switched telephone network in some cases, or whether the distribution is limited to points within the local cable service area. If the information must be transmitted through a larger network, such as a state, regional, or even national facility, then the specifications may be quite stringent.

Basically, institutional cable design technique is for a two-way trunk system with no feeder amplifiers extensively employed. All the engineering considerations that we have discussed earlier, such as frequency response, noise, intermod, etc., will be equally applicable to institutional cable plant design. One significant difference may be when the private signals are expected to be digital in nature rather than analog as television or audio transmissions usually are in CATV operations. We will discuss digital transmission in depth later when we consider Local Area Network (LAN) applications.

Although the actual utilization of institutional cable plant is somewhat uncertain in many installations, the cable placement during the construction of the CATV system is a wide spread practice because of the cost economies such a procedure presents. The institutional plant may not be amplifier equipped or energized initially, but the cable itself is often placed anyway on the expectation of delivering new services and earning new revenues.

Plant Extension in CATV Systems

Many CATV systems that are fully operational, some even for years, still have growth potential in nearby areas or communities. As satellite program delivery increases the number of channels a system can offer, the level of public awareness and interest in the service increases.

Residential developments three or four miles outside a CATV operators service area can represent a very attractive opportunity for additional revenue.

The economical practicality of some extensions may be marginal because of limited population density in the new area, or because the system operator approaches every such instance only from the perspective of past experience with trunk-feeder system designs. In many cases, the cost of trunk-feeder plant extensions will be prohibitive for system growth. There are no technically disqualifying reasons why plant extensions could not employ the less expensive single-cable design, and in many cases we may find the cost advantage such, that system growth opportunities that were previously considered to be un-economic, may now be possible. We may have to consider different operational signal levels for the extension plant, but our study of single-cable design techniques has prepared us to do just that.

In an earlier chapter we developed input and output signal levels to optimize system extension or "reach," always conscious of the obligations of system performance specifications. An extension of existing plant must be addressed in a different manner but compliance with specifications must still be observed. In considering an extension, we must first determine the required or desired length of the extension in amplifier cascade, and consider all required passive device insertion losses and cable splitting.

Then we must establish the end-of-system performance that we are prepared to accept at the extremities of the plant extension. These specifications may or may not be the same as those in force for the existing CATV operations. If the new service area was restricted or included only a small number of new subscribers, we might consider relaxing the original specifications somewhat.

In any event, we must evaluate the transmission performance through the existing plant to the point at which the plant extension must originate. This may be done by actual measurements or by calculations using the conventional engineering practices we have been applying throughout the text. Calculations must consider all the factors such as channel loading, input and output levels, amplifier cascade, etc., but none of these are unfamiliar to us. What we need to know is what the C/N ratio and intermodulation distortion is at the point where the proposed new construction will be fed from. As in our previous developments, we will restrict ourselves to X-Mod distortion, but applications involving heavier channel loading may be more appropriately addressed on the basis of Composite Triple Beat distortion. In any event, the methodology has been presented earlier in this text.

If we assume that the point from which the new extension will be fed will be somewhere along the existing trunk, not from the end of a feeder cable, then we can anticipate that at this point of feed the C/N ratio will be close to the end-of-system specification but the intermod performance will not. This reflects the intermod contribution that was reserved for the usual feeder plant extension through a bridger and two line extender amplifiers. We can expect to find this condition in any conventional trunk/feeder system.

If we establish the system performance at the point of new extension and then compare that with the specified end-of-system performance, we can determine how much noise and distortion would be acceptable from the new plant without violating the original system specifications. For example, assume that the original end-of-system specifications called out 43 dB C/N ratio and -52 dB X-Mod. Let us further assume that the performance at the proposed point of extension is found to be 46 dB C/N and -61 dB X-Mod. Any extension that is constructed from this point can be allowed to degrade the C/N by 3 dB, from the established 46 dB to the originally specified 43 dB, and to degrade the X-Mod by 9 dB from the established -61 dB to the originally specified -52 dB.

The actual transmission performance at the interface point would depend to a large extent on the location of that point within the original system, of course. If it were close to the point of system origination, the head end, it would have accumulated little noise or intermod and would permit substantial extension length. If it were out in the system near the end of a trunk cable, it may not be quite as satisfactory.

We might consider an alternative. Although the original specifications are explicit, we might relax the requirements for the extension alone. Presumably the original specifications anticipated that a large number of service points would be encountered at the system extremities. Since a significant percentage of subscribers would have been so served, there was a compelling need to preserve high quality transmission at the system extremities. However, a limited extension of the system will serve relatively few homes, particularly at the extremities of the extension. Somewhat lower performance specifications may be acceptable under such conditions, perhaps even more so if the alternative was no cable service at all. The reader should not interpret this as endorsing the relaxation of specifications, but this is an available alternative.

If we do determine the allowable performance of the extension, and we know its length, how do we proceed with extension engineering? In our example, the remaining margin for noise was 3 dB, and for X-Mod, 9 dB. Since the C/N ratio of an amplifier can be improved by operating at higher input signal levels, and since we have less remaining margin for noise than for intermod, we will consider operating the extension plant amplifiers at higher input levels than the already in-place trunk amplifiers. If we do so and use higher gain amplifiers than the existing trunk units, as we did earlier in the rural system designs, the extension units will contribute higher X-Mod than the existing trunk amplifiers do. But at the point where the extension is fed we have a substantial remaining margin for intermod contribution.

The higher transmission levels, higher than the existing trunk plant at least, will allow greater tapping efficiency along the plant extension or could permit maximum extension length, or some combination of both. The higher levels may also be utilized to economic advantage in using a smaller size, lower cost cable for the plant extension. How do we establish optimum operating signal levels for the extension amplifiers?

The original specifications called for a 43 dB C/N ratio, and we know the C/N ratio at the point of extension origination to be 46 dB. If the extension itself produces a 46 dB C/N ratio, when combined with the existing 46 dB ratio, we would produce an entirely compliant end-of-extension performance of -43 dB C/N. We could verify this by using the chart given in Figure 4-4 for combining power ratios.

The original specifications called for -52 dB X-Mod, and we know the X-Mod at the point of extension origination to be -61 dB. The chart given in Figure 5-2 for combining voltage ratios shows that X-Mod of -56 dB in the extension plant, when combined with the -61 dB in the existing plant, will produce a fully compliant -52 dB at the end of the extension.

We will assume that amplifiers are available that, at a +8 dBmV input, produce 57 dB C/N ratio. These same units, carrying 21 channels, will produce -83 dB X-Mod at an operating output level of +40 dBmV. If the proposed extension required as many as 16 amplifiers in cascade, then the transmission performance of the extension plant alone will be:

$$
\begin{aligned}
C/N_{sys} &= C/N_{amp} - 10 \log N \\
&= 57 - 10 \log 16 \\
&= 45 \text{ dB} \\
XM_{sys} &= XM_{amp} + 20 \log N \\
&= (-83) + (20 \log 16) \\
&= -59 \text{ dB}
\end{aligned}
$$

If we actually operate the extension amplifiers at these levels, we have better than the required X-Mod contribution but we do not meet our requirements for noise. But we are perfectly free to manipulate the operating levels so as to produce less noise and more X-Mod. If we raise input and output levels by 1.5 dB, the C/N ratio would improve from 45 dB to 46.5 dB, and the X-Mod would degrade 3 dB from -59 dB to -56 dB. Combining this extension performance with the portion of the system that is operating in cascade with the extension, we will be in full compliance with the original noise and intermod specifications.

Using .500 inch cable loss at 220 MHz, and assuming four subscriber taps per mile of plant, 16 amplifiers could accommodate a plant extension of approximately 7 miles, serving subscribers along this length and still being fully compliant with the original system specifications. At 300 MHz, carrying 35 channels, the extension could still be a respectable 5.5 miles or so. Note that we might have increased the extension length or "reach" if we had chosen to relax the end-of-extension specifications slightly.

In this example we modified the operating levels by 1.5 dB to manipulate the noise and intermod performance. We did not change amplifier gain. We could have made a more significant change in operating levels if it had been necessary. For example, if the point of extension origination had been farther away from the system head end, and thus had presented a lower level of transmission quality to start with.

The figures we used in this example were arbitrarily selected for demonstration purposes but the methodology is clear. We cannot expect to achieve substantial system extensions at all points along the trunk, and trunk extremities will be somewhat less extendable. However, transitioning to the less expensive single-cable design will always allow some extension, and even so small an extension as perhaps five amplifiers may be useful in reaching previously unserved pockets of subscribers. It is possible to "stretch" the extension "reach" by using lower-loss, larger-size cable, of course, but this would increase extension cost somewhat. However, even this approach may prove to be less expensive than a trunk-feeder design extension. Combining the two design techniques in a single system can be useful as we have seen, and it need not compromise system specifications at all.

Small Community System Design

The single-cable design that we discussed in an earlier chapter produces significant cost advantages over a trunk-feeder design, particularly when applied in the out of town sections of rural systems, but the design does reduce subscriber tapping efficiency. This deficiency reduces the cost savings that single-cable designs may produce in the in-town plant though in many cases it will still be less expensive than a pure trunk/feeder design. In smaller, marginally economic systems, we may find that long-term operating cost reductions are as important as initial system construction costs.

With this in mind, we might consider a modification of the single-cable design, basically a change in operating signal levels to improve the efficiency in the in-town portions of small systems while still permitting the use of one single amplifier type throughout the entire rural system. Even if we have to introduce a second set of operating levels but still used the same amplifier, the logistics might be attractive.

A standard unit of equipment would reduce maintenance spare parts stocking as well as simplifying testing procedures. In rural systems the in-town portion of the plant will be a very small portion of the total plant required, and we might still reduce the in-town costs below that of a trunk/feeder design.

Most generally a small community will be located at or near the center of the rural service area, and we will designate this as a "core" community. It would be physically close to the system head end, typically, and several studies indicate that such a core community will contain fewer than 1,000 residences in most cases. Without question, a trunk plus feeder design can accommodate such a community, and many such small systems have actually been constructed.

But the trunk/feeder design requires a variety of equipment types as earlier studies have shown, as well as introducing several transmission levels.

For example, in addition to perhaps two types of trunk amplifiers (manual and automatic gain control), we may need two or three types of bridging amplifiers plus line extender units. The basic mixture may be as many as five different types, compared to at most two, manual and AGC, in a single-cable system. And in many smaller systems, only one or two bridger units would be utilized in the entire system anyway, which certainly complicates spare parts stocking. Most significant, however, is the fact that the basic economical advantage that the trunk/feeder design can offer cannot be extensively enjoyed since the tapping load is only nominal and the total plant requirement is distinctly limited.

The single-cable design, as we discussed it earlier, utilized amplifiers offerring 32 dB of usable gain and operating at a +40 dBmV output level. This output level was selected in response to the relatively long rural cable routes we anticipated serving. But in the core community, since we are quite close to the system head end, we are certainly free to raise this output level providing only that we do not violate end-of-system transmission specifications. What happens if we do just that, not change amplifier gain, but just change operating levels?

At +40 dBmV output, carrying 21 channels, the amplifiers produced -83 dB of X-Mod. Since X-Mod will increase 2 dB for every 1 dB increase in output level, given the same channel loading, if we raise the outputs to +45 dBmV the X-Mod would degrade to -73 dB. The higher output level, with no change in amplifier gain, would simply improve the C/N ratio by 5 dB. The +45 dBmV output begins to approach the output levels of the trunk/feeder design line extender amplifiers, and the higher transmission levels will significantly improve the tapping efficiency, at least throughout the in-town portion of the system where we propose to use them.

In regard to the increased intermod distortion, since the in-town plant is limited in scope, we can certainly accept some increase in intermod. After all, it would not be worse than what we were prepared to accept at the end of any trunk/feeder system.

Operating the amplifiers at this higher level will not be appropriate for the out-of-town cable routes since this would distinctly limit the system "reach," and here we will retain the +8 dBmV input and +40 dBmV output that we previously established to be optimum for that application. Note that in this application, although we have two different operating levels involved, we can use the identical amplifier throughout the entire system. We are simply operating the unit at different levels.

Assuming we do this, just how many high output units can we tolerate in cascade? The amplifier produced -83 dB X-Mod at +40 dBmV output carrying 21 channels. At +45 dBmV output this figure becomes 10 dB worse, or -73 dB. If the system X-Mod specification permitted -52 dB X-Mod, then a cascade of 11 such units would be acceptable, from:

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-73) + (20 \log 11)$$

$$= -52.5 \text{ dB}$$

A cascade of 11 units spaced 1,900 feet apart including some estimated tap insertion losses, would still "reach" about 3.9 miles, certainly more than sufficient to span the small communities we are discussing here. By our earlier definition the core community was located relatively near the head end and was identified to be quite small. The modified single-cable design would be very cost-effective in such situations.

We cannot transition to higher operating levels without considering the effect on the longer, out-of-town rural sections of the system. When a cable route must pass through the community and be extended out into the rural area we will operate that route at the previously established, lower signal levels so as to not compromise the performance of the rural plant. This may even entail some parallel cable placement in some cases, but such cases should be limited and infrequent. The lower signal level cables would not be tapped for subscriber service in-town, further extending the rural system plant.

It is difficult to determine with precision just which particular applications can effectively employ the single-cable design. Several dual design efforts were undertaken by the author, using both trunk/feeder and single-cable techniques, and the results seem to indicate that in communities with fewer than 1,500 homes or so, the single cable system will always be more economical. The line of demarcation is not precise.

However, it has been established without question that single-cable designs will always be more economical in the out-of-town portions of rural systems. Note that although the high-level, single-cable technique does introduce a second set of transmission levels, somewhat complicating system operations and maintenance, this same penalty, to a much higher extent is inherent in any trunk/feeder system. Even with two sets of transmission levels, the single-cable design utilizes identical amplifiers throughout the entire plant.

LAN and Special Service Systems

Coaxial cable transmission facilities present substantial spectrum for private use, as opposed to spectrum in free space which is for public use such as commercial broadcasting. Although this text has focused primarily on Cable Television utilization of coaxial cable plant, the technology lends itself quite well to the transmission of data, video, or voice services in private communications networks. Such networks might be defined as LANs (Local Area Networks) or WANs (Wide Area Networks).

We define a LAN as being a two-way or bi-directional transmission facility that is somewhat restricted in service area, typically extending throughout a campus or industrial park, and usually serving a multiplicity of work stations that are randomly distributed throughout the service area.

We define a WAN as serving a much larger geographic area in much the same way, and often a WAN will include smaller LANs that are interconnected into the larger network structure.

The nature of these networks is quite similar to a conventional CATV operation in that a multiplicity of service points are connected to a central point, or system head end. The technology of RF carrier transmissions over coaxial cables, and the use of amplifiers and taps to structure the network, is identical with that employed in CATV systems. One basic difference is that LANs or WANs are always two-way operations whereas CATV systems may or may not be bi-directional, and the second major difference is in the nature of the information that is transmitted through the LAN or WAN.

In CATV operations the information to be transported are television signals, each of which, in an AM type system occupies about 6 MHz of transmission system spectrum. All system engineering calculations are based upon this 6 MHz bandwidth, and as we will learn in the next chapter, even return transmission calculations for two-way systems are generally based upon video transmission bandwidths. Analog signals such as AM television signals are quite vulnerable to noise and distortion products, whereas the signals usually applied to LANs are digital in nature and are less susceptible to these factors. Also, the digital signals employed usually occupy substantially less spectrum per signal than a television signal would, so the mechanisms of noise contribution will be different than for a television transmission system.

It is possible and convenient to develop transmission engineering for LAN systems based upon the 6 MHz channels that we are so familiar with from CATV activities. If we do so, then the transmission specifications for LAN applications will employ the same basic television criteria such as triple beat, composite triple beat, C/N ratio, etc. We must recognize some differences however, and these do relate to the basic principles that we have been discussing throughout this text.

For example, if we pass many more signal carriers through an amplifier used in an LAN, then the intermod distortion will be significantly worse, just as it was when we added television signals to a CATV system. We can alleviate the intermod contribution by simply reducing the amplitude of the signal carriers, again, just as we did in the television transmission systems.

Then we might engineer an LAN application in the same manner that we do a television application, but we must now identify the number of LAN data or other service digital carriers that may be present in any 6 MHz portion of the system bandwidth, and reduce the amplitude of each such individual carrier in a rational manner so that the end-of-system performance will be acceptable. There is a correlation that can be made between the C/N ratio of a 6 MHz channel and a digital signal operating within that same spectrum but it is beyond the scope of this text to pursue this in depth. Acceptable digital transmission quality can often be produced through analog transmission facilities that present C/N ratios on the order of 25 dB or so, a grade of service that we would find totally unacceptable in a CATV system.

When many digital carrier signals are positioned within a 6 MHz bandwidth that we previously utilized for only one television carrier, we can calculate the maximum amplitude that we can tolerate from each individual digital carrier as follows:

$$Sig_{dig} = Sig_{vid} - 10 \log N_{dig}$$

where Sig_{dig} = Amplitude of each digital carrier (dBmV)

Sig_{vid} = Amplitude of the video carrier (dBmV)

N_{dig} = Total number of digital carriers involved

If we derate the amplitude of all digital carriers in this manner, then the development of the LAN design on a basis of television performance in 6 MHz channel bandwidths is valid. Since many LANs require the transmission of some television signals along with the digital transmissions, developing the system design based on television channel performance is both convenient and practical.

By definition, the length of a LAN system is limited. This suggests that the use of trunk plus feeder design philosophy may not be appropriate in many instances. We could offset the tapping inefficiency of a single-cable design by simply using larger-size, lower-loss cables since the cable lengths will be nominal and the amplifier cascade in most LANs is distinctly limited. This suggests that a single-cable design, perhaps at higher output levels, will be most appropriate. Certainly the logistical advantages of a single type of amplifier throughout with identical operating signal levels would be attractive.

In any event, the amplifiers, taps, and other devices used in coaxial LAN or WAN networks are identical with those units used in conventional CATV systems; and all design, construction, and maintenance practices will be also. Special service systems such as LANs may be single-cable bi-directional installations or they may utilize a separate cable for each direction of transmission, depending upon the amount of data to be transported and the number of work stations to be accommodated.

Summary

This discussion of other types of systems is somewhat limited but it does reinforce our earlier studies of RF transmission systems. If we thoroughly understand the basic principles involved and the relationship between such factors as noise, intermod distortion, etc., we can readily modify or adapt any design philosophy to satisfy a wide range of applications.

Chapter 17

Two-Way System Design

The range of services possible on coaxial cable systems can be dramatically expanded by introducing bi-directional (two-way) transmission capability. The hardware and the technology have been available for years, and almost without exception, all systems constructed today are either so equipped initially or are capable of subsequent upgrade through the use of plug-in accessory equipments.

Coaxial cable RF transmission systems are wideband in nature, and essentially all that is required is to suitably sub-divide the available system bandwidth, allocating some spectrum for transmission in the reverse (upstream) direction. The upstream transmission will also be wideband in nature and will require periodic signal reamplification due to cable and other transmission losses in the system. All of the technical considerations and factors we have discussed so far will apply equally to the upstream transmission system. Gain and loss, noise and intermod distortion, equalization, etc., all are involved, and all must be addressed in system engineering.

General Discussion

In the early development of two-way transmission, it was generally assumed that upstream transmissions would most probably involve television signals. The popular scenario was the origination of video/audio signals at various points throughout the system, transmission back through the system to the head end, and re-transmission back down the system to all CATV subscribers. The development of new services and the introduction of more sophisticated CATV operations has led the evolution in quite another direction.

Interactive subscriber terminals, capable of transmitting digital data back to the head end, have introduced an entirely new perspective. Perhaps most of the return signals may not be video in nature at all, and there may be only a limited necessity for most return transmissions to be retransmitted downstream.

Where engineering consideration was focused on television transmission from the most distant system extremity, back to the head end and then out to the extremity again, this sequence of operation, sometimes called loop back, becomes somewhat less probable.

It can be argued quite logically that using television signal oriented design criteria and performance specifications, such as intermod, noise, etc., is inappropriate. This is true to some extent, but it is equally true that developing and applying other criteria might be equally inappropriate. The development of the new services is still quite embryonic, data bit rates and transmission standards are undefined as yet, and even modulation techniques are subject to debate. If we are premature in establishing any new design criteria, it may well prove inadequate or excessively conservative at some later date.

There is some consensus, however, that television transmission requirements are more stringent than any new service is likely to require. For these reasons, most two-way engineering and design is still based upon television transmission. Upstream transmission capacity is stated in channels, and C/N ratios and X-Mod or other forms of intermodulation distortion are still utilized, both in equipment specifications and in design calculations, even though the major utilization of two-way capability may not be television transmission at all.

Basic Two-Way Technology

The basic technology is frequency division of spectrum by means of filters. Examine the two-way filter in Figure 17-1. At the common terminal of the filter the entire transmission spectrum is available, 5 to 300 MHz in this example. This common terminal would be the point to which the interconnecting coaxial cable would be connected. The terminal identified as "High Frequency" is the output port of a high-frequency bandpass filter. Low-frequency signals presented at either the "Low Frequency" or the "Common" terminals of the filter will be rejected by the high impedance presented to low-frequency energy by the high frequency side of the filter. High-frequency signals applied to either the "Common" terminal or the low-frequency terminals will be rejected by the low-frequency bandpass filter.

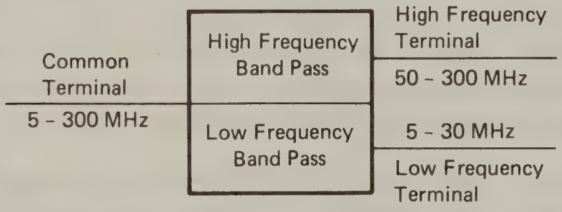


Figure 17-1 Two-Way Filter

High-frequency energy will pass freely through the filter in either direction, but only between the common and high-frequency terminals. Low-frequency energy will pass freely through the filter in either direction, but only between the low-frequency and common terminals.

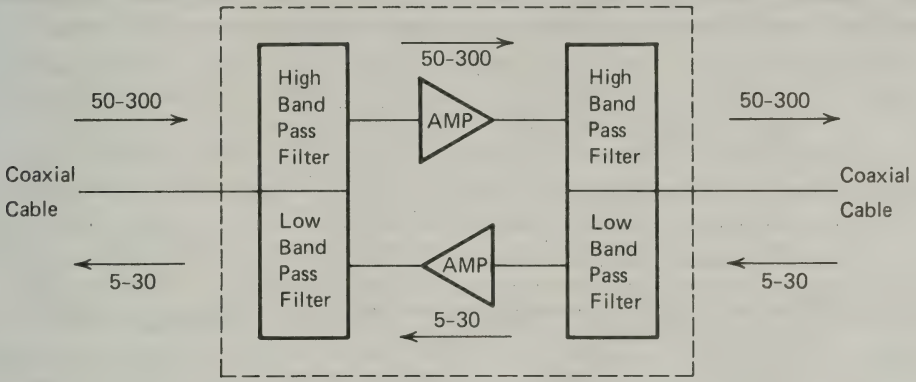


Figure 17-2 Two-Way Amplifier

In Figure 17-2 we show a two-way amplifier equipped with 2 two-way filters. The 50 to 300 MHz band is the high-frequency transmission spectrum, and the 5 to 30 MHz spectrum the low. Any high-frequency signals presented to the common terminal of the two-way filter appear at the high bandpass filter output, pass through the high-frequency amplifier, and are presented to the high-frequency port of the second two-way filter. Any 50 to 300 MHz signals, amplified, are launched into the coaxial cable from the common terminal of the two-way filter and will propagate down the cable to the next equipment location.

Low-frequency signals are directed through and amplified within the unit in a similar manner. Thus, the two-way amplifier, inserted into a single coaxial cable, provides two distinctly separate bands of spectrum for transmission of information in both directions simultaneously. The frequency response characteristics of both the "High" and "Low" bandpass filters establish the transmission bandwidths available for both upstream and downstream transmission, and also provide a suitable guard band for isolation between the transmission bands. At the system head end or at any other suitable point in the system, a two-way filter will isolate and provide individual access to, either upstream or downstream transmission spectrum.

Noise Contribution in Two-Way Systems

Although individual amplifier noise contribution and C/N ratio is developed precisely the same for return or upstream amplifiers as it was for downstream equippment, there is a very significant difference in two-way systems.

In the downstream application, the total noise accumulated was a combination of the noise power introduced only by those amplifiers the signals had actually passed through. For example, although a system may have as many as 250 total amplifiers, noise would only accumulate through the longest single transmission cascade. If the worst-case cascade were 25 units, then noise calculations need only consider the contribution of these 25 units in establishing the worst-case, end-of-system C/N ratio.

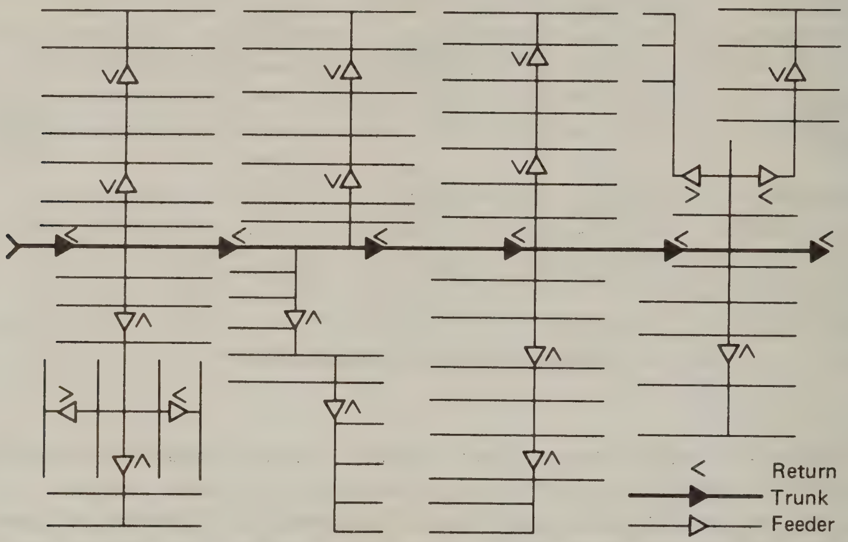


Figure 17-3 Trunk/Feeder System

In a two-way system all return amplifiers in the system contribute noise to a common reception point, the system head end. In Figure 17-3 we show a small section of a trunk/feeder system. The small arrow placed alongside each amplifier denotes the return transmission direction. Note that all arrows point towards the point of system origin. If these are return amplifiers and are all energized, as they would be in a two-way application, the noise power generated in each unit would accumulate and be presented to the system head end.

Perhaps a simpler way to envision this is to consider each return amplifier as an individual noise generator. At all times, even in the absence of input signals, all return amplifiers are actually generating noise, and the output of all amplifiers is concentrated or collected and presented to the system head end. Obviously there is some summing up of all these noise generator outputs that can produce significant noise in the return transmission path at the head end.

We must consider noise in the return system as being a product not only of the cascade of return amplifiers that signals must pass through on their trip to the head end, but as a product of the total number of upstream amplifiers (noise generators) in the system, wherever they may be physically located and whether or not the signals actually pass through them. In practice, this requires us to complete the downstream layout before we can accurately calculate the upstream transmission performance, since we must know not only the cascade of return amplifiers to be passed through, but the total quantity of return amplifiers as well. In many two-way systems this would involve one return amplifier for every single amplifier in the entire cable network.

Given these numbers for both the trunk plant and the feeder plant separately, we can calculate the upstream X-Mod and noise performance using operating signal levels, and combine these results with the downstream performance (noise and intermod) to determine worst-case, loop-back transmission quality through the entire system.

Intermodulation distortion through the upstream system is still only a function of the number of amplifiers the signals are actually passed through, since no intermod can be accrued unless the signal actually does pass through an amplifier. We can calculate upstream X-Mod precisely the same way we did for the downstream transmissions with due regard for output signal levels, channel loading, and amplifier output specifications. Perhaps some example calculations would be helpful.

Upstream Noise Calculation

For our example we will assume the system includes all of the following:

A total of 250 return trunk amplifiers.

A longest trunk amplifier cascade of 26 amplifiers.

A total of 1,250 return feeder amplifiers.

A longest feeder amplifier cascade of two amplifiers.

We will assume an allowable upstream C/N ratio of 44 dB, but unlike the downstream design where we could simply ignore the noise contribution from the feeder plant because it was so small, in the upstream calculations we can anticipate a significant noise contribution from the feeder plant since there are 1,250 feeder amplifiers involved.

Since the allowable C/N ratio for the entire upstream system is 44 dB, we will arbitrarily allocate a 46 dB C/N ratio to the upstream trunk amplifiers and a 50 dB C/N ratio from the upstream feeder plant. From Figure 4-4 we can see that combining these two ratios (46 dB and 50 dB) will result in a total upstream C/N ratio of 44 dB or better, compliant with the requirement.

For all upstream calculations we must establish an equivalent amplifier cascade that will reflect the noise contribution from both the cascade of amplifiers passed through, and the noise from the total number of return amplifiers. One approach is to apply the following formula:

$$C_{eq} = \sqrt{N \times M}$$

where C_{eq} = Equivalent cascade of amplifiers

N = Total number of amplifiers in network

M = Total number of amplifiers in cascade

In the trunk system in our example we had a total of 250 trunk amplifiers involved and a cascade of 26 amplifiers. The total noise contribution of this combination would be the same as the noise contribution from a straight line cascade of 81 trunk amplifiers, as determined from:

$$C_{eq} = \sqrt{N \times M}$$

$$= \sqrt{250 \times 26}$$

$$= 80.62 \text{ or } 81$$

Given the noise figure of a single return trunk amplifier and the input signal applied to that amplifier, we can establish the C/N ratio of this equivalent cascade (81 units) as it would be produced at the end of the return trunk transmission system at the head end.

Assume a noise figure of 7 dB and an input signal level of +13 dBmV. The C/N ratio per amplifier would be calculated just as we did earlier, as:

$$C/N_{amp} = Sig_{in} + 59 - NF$$

$$= (+13) + 59 - 7$$

$$= 65 \text{ dB}$$

A cascade of 81 such amplifiers would produce:

$$
\begin{aligned}
C/N_{sys} &= C/N_{amp} - 10 \log N \\
&= 65 - 10 \log 81 \\
&= 45.9 \text{ or } 46 \text{ dB}
\end{aligned}
$$

Having determined the C/N ratio for the upstream trunk transmission system, and in this case we have done only the trunk so far, we could combine this with the upstream feeder C/N ratio and then further combine with the downstream system C/N ratio, establishing the worst-case, loop-back transmission performance from a system extremity back to the head end and then downstream to the same system extremity again. The process is tedious but not difficult, and to reinforce our understanding, let's do the calculations for a complete trunk/feeder system, including the loop-back performance.

System Performance Calculations

We will use the same equipment quantities we used in the earlier calculations, and specify the individual amplifier performance to be as follows:

Downstream Trunk Amplifier	
-57 dB X-Mod with 21 chans. at	+48 dBmV output
Noise Figure	10 dB
Usable gain	23 dB
Downstream Feeder Amplifier	
-57 dB X-Mod with 21 chans. at	+52 dBmV output
Noise Figure	10 dB
Usable gain	26 dB
Upstream Trunk Amplifier	
-57 dB X-Mod with 4 chans. at	+50 dBmV output
Noise Figure	7 dB
Usable gain	17 dB
Upstream Feeder Amplifier	
-57 dB X-Mod with 4 chans. at	+50 dBmV output
Noise Figure	6 dB
Usable gain	23 dB

Earlier in the text we have discussed the selection of operating signal levels, and to simplify the calculation process here, we will simply call out arbitrary operating levels for the downstream transmission system to be:

Downstream Trunk Amplifier Input	+9 dBmV
Downstream Trunk Amplifier Output	+32 dBmV
Downstream Feeder Amplifier Input	+23 dBmV
Downstream Feeder Amplifier Output	+47 dBmV

We will assume the loop-back operation (downstream plus upstream transmission) performance specifications are 41 dB C/N ratio and -51 dB X-Mod.

The downstream trunk performance may be calculated as:

$$C/N_{amp} = Sig_{in} + 59 - NF$$

$$= +9 + 59 - 10$$

$$= 58 \text{ dB}$$

A cascade of 26 units would produce:

$$C/N_{sys} = C/N_{amp} - 10 \log N$$

$$= 58 - 10 \log 26$$

$$= 44 \text{ dB (trunk only)}$$

The downstream feeder C/N ratio will be sufficiently high, given an input signal level of +23 dBmV, that it will have no signifigance, thus the trunk C/N ratio of 44 dB may be taken as the downstream system C/N ratio.

The downstream trunk X-Mod may be calculated as:

$$XM_{amp} = XM_{spec} + 2\,(OL_{oper} - OL_{spec})$$

$$= (-57) + 2\,(32 - 48)$$

$$= -89 \text{ dB}$$

A cascade of 26 units would produce:

$$XM_{sys} = XM_{amp} + 20 \log N$$

$$= (-89) + 20 \log 26$$

$$= -61 \text{ dB}$$

The downstream feeder X-Mod may be calculated as:

$$XM_{amp} = XM_{spec} + 2\,(OL_{oper} - OL_{spec})$$

$$= (-57) + 2\,(47 - 52)$$

$$= -67 \text{ dB}$$

A cascade of 3 units would produce:

$$XM_{sys} = XM_{spec} + 20 \log N$$

$$= (-67) + 20 \log 3$$

$$= -57.5 \text{ dB}$$

Using the chart in Figure 5-2 combining -61 dB and -57.5 dB would produce a total downstream X-Mod of -53 dB. The downstream C/N ratio has been established to be 44 dB.

If the loop-back specifications are 41 dB C/N ratio and -51 dB X-Mod, and the downstream performance is -53 dB X-Mod and 44 dB C/N ratio, the allowable contributions from the upstream plant can be established, using the charts in Figures 4-4 and 5-2, to be 44 dB C/N and -65 X-Mod.

We will arbitrarily allocate a C/N ratio of 50 dB to the upstream feeder plant and 46 dB to the upstream trunk plant which, when combined, will produce the permitted 44 dB C/N ratio for the total upstream system. We shall have to determine an equivalent cascade of both trunk and feeder return amplifiers before we can complete the calculations.

The equivalent cascade of upstream trunk amplifiers may be established from:

$$C_{eq} = \sqrt{N \times M}$$

$$= \sqrt{250 \times 26}$$

$$= 81 \text{ amplifiers}$$

The equivalent cascade of upstream feeder amplifiers may be established from:

$$C_{eq} = \sqrt{N \times M}$$

$$= \sqrt{1250 \times 3}$$

$$= 61 \text{ amplifiers}$$

The input signal level required for a cascade of 81 upstream trunk amplifiers to maintain a C/N ratio of 46 dB may be determined from:

$$Sig_{in} = NF + C/N_{sys} + 10 \log N - 59$$

$$= 7 + 46 + 10 \log 81 - 59$$

$$= +13.08 \text{ or } +13 \text{ dBmV}$$

Given 17 dB of gain, an input level of +13 dBmV will produce an output level of +30 dBmV. The X-Mod for a cascade of 26 trunk amplifiers operating at +30 dBmV output may be calculated as:

$$XM_{sys} = XM_{spec} + 2\,(OL_{oper} - OL_{spec}) + 20 \log N$$

$$= (-57) + 2\,(30 - 50) + 20 \log 26$$

$$= -69 \text{ dB}$$

The input signal level required for a cascade of 50 upstream feeder amplifiers to maintain a C/N ratio of 50 dB may be determined from:

$$Sig_{in} = NF + C/N_{sys} + 10 \log N - 59$$

$$= 7 + 50 + 10 \log 50 - 59$$

$$= +14.98 \text{ or } +15 \text{ dBmV}$$

Given 23 dB of gain, an input level of +15 dBmV will produce an output level of +38 dBmV. The X-Mod for a cascade of 3 feeder amplifiers operating at +38 dBmV output may be calculated as:

$$XM_{sys} = XM_{spec} + 2\,(OL_{oper} - OL_{spec}) + 20 \log N$$

$$= (-57) + 2\,(38 - 50) + 20 \log 3$$

$$= -71.5$$

We can combine upstream amplifier performance as:

Upstream Trunk C/N ratio	46 dB
Upstream Feeder C/N ratio	50 dB
Combined Upstream C/N ratio	44.5 dB

Upstream Trunk X-Mod	-69 dB
Upstream Feeder X-Mod	-71.5 dB
Combined Upstream X-Mod	-64 dB

We can combine this performance with the previously established downstream performance as:

Downstream C/N ratio	44 dB
Upstream C/N ratio	44.5 dB
Loop Back C/N ratio	41 dB

Downstream X-Mod	-53 dB
Upstream X-Mod	-65.5 dB
Loop Back X-Mod	-51 dB

Both are fully compliant with our original specifications. The purpose of this exercise was to familiarize the reader with the methodology and to demonstrate system design analysis technique, as well as to exercise the reader in the use of the formulas previously discussed.

Note that in a single-cable design, the calculations would be less complicated since we do not have two separate sub-systems (trunk and feeder) to consider. In effect a single set of calculations would be all that is required.

Of course the numbers used here were selected for demonstration purposes, and even though we pursued all intermodulation distortion calculations on the basis of X-Mod, the same methodology would apply if the system had been a wider bandwidth facility and the intermodulation concern had been Composite Triple Beat.

Analysis of System Calculations

Assuming the figures we used in the example above were from an actual system layout, just how large a system would that involve? We had called out a total of 250 trunk stations and 1,250 feeder amplifiers. If the system had enjoyed a 4-to-1 feeder-to-trunk ratio and we assume three trunk amplifiers per cable mile, then there would be 84 miles or so of trunk plant and about 336 miles of feeder plant. This would be a rather extensive rural system but not unusually large at all for an urban system.

We can tabulate the individual system element transmission performance as follows:

Carrier-to-Noise Ratio

Downstream Trunk	44 dB
Downstream Feeder	N/A
Upstream Trunk	46 dB
Upstream Feeder	50 dB

Cross Modulation Distortion

Downstream Trunk	-61 dB
Downstream Feeder	-57 dB
Upstream Trunk	-69 dB
Upstream Feeder	-75 dB

One of the practical aspects of tabulating the loop-back performance as individual elements, as we have done above, is if it became necessary to manipulate any system signal levels for the purpose of improving performance that perhaps had not been in compliance with specifications, the options for readjustment could be easily identified.

Interactive System Operation

The term interactive, as we use it here, refers to the capability of a subscriber station anywhere within the system to interact with the system head end through direct and individual communications between that service location and the head end. This, of course, requires bi-directional transmission capability but there is a bit more to it than that. Recovering information from a multiplicity of subscriber terminals within a system could be accomplished in two basic ways.

The first would be a full-time, available-on-demand "talk-back" capability from each station. The best example of this type of operation is the individual private line telephone service we are all so familiar with. Whenever the subscriber lifts the handset off the switch-hook, he is assured immediate access to the switching center. After selecting by dialing, any one of perhaps thousands of other individual subscribers lines, the transmission path between the two is established. The transmission is two-way and uninterrupted, that is, either or both subscribers can talk at the same time. Thus the term "full talk" is often used and is quite appropriate. This condition is set up and available whether anyone else along the same cable route or within the same switching exchange is also using their telephone or not.

For many types of interactive service a "full talk" capability is not necessary. In an alarm reporting system it might be quite acceptable if the actual transmission of the alarm condition were delayed for several seconds. This is equally true of meter reading or electric power load management systems, pay television service ordering, and others.

For such applications we might simplify the entire system by utilizing an "interrogation" type of operation. Under such a system, only one individual station is addressed at any given moment in time. This is done by transmitting a digital pulse train and individually addressing single stations, although all stations may actually receive the signal by digitally encoding a discrete address for each and every station. If we can address a single station, then we can also enable only one station at a time to actually respond or "talk back." This might be considered analogous to party-line telephone service where only one subscriber at a time can utilize the facilities.

With todays technology we can do this digitally at a very high data rate, and thus thousands of stations can be interrogated quite rapidly, say in a matter of a minute or so. Since the interrogating signal is the same for all stations, only one transmission carrier frequency is required for all downstream transmissions and all station receivers can use the same receiving frequency, making it very cost-effective. Since only one station transmits back to the head end at any given instant, all station transmitters can also be designed for the same carrier frequency.

The reader should not confuse the interrogation or time sharing technique with the more sophisticated "full-talk" level of operation. To accommodate the out-of-service periods that every station will encounter, that is, those periods when it is not authorized or enabled to transmit, terminal equipment can be equipped with microprocessors or memory capability that can record data or status changes until such time that the central terminal does interrogate that station, at which point the terminal transmits its stored data to the central station.

The provision for interactive capability in this manner is quite satisfactory for many functions and services, but it is not suitable for voice telephone service on a "full-talk" basis. The possible configurations and uses of interrogative terminals include various control capability or operational status reporting for the system amplifiers themselves. We simply equip all amplifiers with similar receiving and transmitting capabity.

The authorization and enabling of signal de-scrambling by discrete subscriber terminal equipments may be accomplished through an interrogative capability such as described here, but the in-depth development of this subject is beyond the scope of this text. The basic capability and technique is, however, evolving along the lines discussed here.

The reader should recognize that when coaxial cable people are talking about two-way transmission systems and capabilities, they are generally not talking "full-talk" capability in most CATV systems, but are discussing interrogative systems of one kind or another.

Noise Reduction Techniques

In an interrogation type of interactive system, only one subscriber station at a time is addressed, and only one responds at any given instant. Since this is so we might dramatically improve transmission performance for the upstream system.

Consider Figure 17-3 for a moment. This block diagram shows 6 trunk amplifiers and 18 feeder amplifiers in a small section of a trunk/feeder system. This small section of plant might be duplicated many times, dozens of times perhaps, in a large urban system, and all the return feeder amplifiers shown in the figure will contribute transmission noise that will be accumulated at the head end receiving location. Note that in our example in the earlier discussion in this chapter, we had to consider noise contributions from 250 trunk amplifiers plus 1,250 feeder amplifiers in the return system.

If it is not necessary to have the entire return system connected to the head end all the time because we are receiving information from only one station at a time, and that station is located out in a very small, single feeder section of plant, then we might disconnect the rest of the return feeder plant at least some of the time. When we address and enable a particular subscriber terminal, we could address not only the individual station but the associated bridger amplifier that originates the feeder cable on which that individual station is located.

All downstream transmission would be unaffected and uninterrupted throughout the entire system, but we could simply disconnect all feeder plant that was not actually required for return transmission service at any given instant in time. That could mean all return transmission capability, except that required to receive signals from the individual station that had been addressed and was authorized to transmit.

Suppose we disconnected every feeder cable in our earlier example except one, and suppose that feeder cable had a total of ten feeder amplifiers on it.

Our earlier upstream feeder C/N ratio was developed from:

$$C_{eq} = \sqrt{N \times M} = \sqrt{1250 \times 2} = 50 \text{ amps.}$$

where N = 1,250 feeder amplifier total
M = 2 feeder amplifier cascade

Now that calculation would be:

$$C_{eq} = \sqrt{N \times M} = \sqrt{10 \times 2} = 5 \text{ amps.}$$

The upstream feeder C/N ratio under these conditions would be about 10 dB better if we used the same input signal level for the return feeder amplifiers because the equivalent cascade was reduced from 50 to 5 units.

This technique, return feeder disconnect, does introduce both cost and sophistication into the amplifiers since each bridger unit must be equipped with a control carrier receiver and decoder to receive the command from the head end controller, and each amplifier must be equipped to disconnect the feeder return transmission paths also. In large systems where very large numbers of feeder amplifiers are involved, this approach may become mandatory, so it is necessary to understand the technology that is available.

Feeder Disconnect and "Full-Talk"

It is possible to retain some degree of "full-talk" return transmission capability while still using the noise limiting techniques of return feeder disconnect. If, for example, a full time video transmission from one point on a single-feeder cable were necessary, the particular bridger amplifier feeding that particular feeder cable would not be equipped for switched disconnect at all. Then the program origination point on that feeder cable would have access for RF transmission back to the head end all of the time, but all other feeder cables in the system could be switch disconnected as necessary to accommodate a second level of interrogative return transmission service.

The noise reduction that is made possible by switched feeder disconnect could be utilized by permitting more noise from the other elements in the system, the downstream or upstream trunk amplifiers for example, which might improve the over-all cost effectiveness of the plant.

Feeder Disconnect in Smaller Systems

The technique of feeder disconnect requires additional sophistication in both the system amplifiers and in the central computer and software necessary to provide addressability and control. In smaller systems the cost penalties of this increased sophistication may often prove inhibitive. Fortunately, in small systems it is not mandatory that feeder disconnect capability be provided. If the total number of system amplifiers is not great, the noise accumulated in the return transmission system may be tolerable. Even in larger, urban installations, feeder disconnect cannot eliminate the return noise accumulation from the large numbers of return trunk amplifiers that are required, and this noise contribution has to be accepted.

It is difficult to state with precision just how many return amplifiers can be tolerated before feeder disconnect must be considered, but it certainly is on the order of several hundred or so, and this should accommodate many if not most CATV applications. Some mitigation of return transmission noise accumulation is possible if the cable feed from the head end can be accomplished with two or three discrete coaxial cables.

The noise accumulation of all system amplifiers under these conditions is distributed between these cables, since the return transmission spectrum is no longer common for all cables. In effect, as regards the return system noise accumulation, the problem becomes two or three smaller systems rather than one very large system.

It should be noted that feeder disconnect prohibits the future use of the plant for "full time" or "full talk" return transmission throughout the entire system. In cases where only interrogative operations are projected, this presents no problem, but if future integration of telephone service is a possibility, or if a large number of private service "full-talk" requirements are expected to develop, perhaps full-service data links for example, then reconsideration of feeder disconnect is necessary.

The digitally modulated signals used in the system both for downstream addressability and communication and for upstream response, are inherently quite a bit less vulnerable to noise than regular video/audio signals are due to the form of modulation employed. Since we anticipate a greater traffic requirement upstream for digital information than for video information, it may not be reasonable to impose ext remely severe loop-back video performance specifications from the most distant system-extremity. If some limited return transmission of video signals is anticipated and the points of origination for such signals are known, then stringent video performance from those particular system locations may be in order, but there is little to be gained by excessively severe loop-back video requirements for the entire system.

Special Considerations in Upstream Design

In the downstream layout process we individually adjust the physical spacing of amplifiers to accommodate the insertion losses of splitters, couplers, and taps. This maintains input and output signal levels consistent with the transmission engineering design although individual amplifier spacings may vary somewhat.

In the upstream layout process we cannot selectively position the upstream amplifier since its location has been dictated by the positioning of the downstream amplifier. The transmission engineering design for the upstream system is a series of calculations as we demonstrated earlier in this chapter, but amplifier gain requirements are a bit more difficult to define because the previous insertion of flat transmission losses such as taps, splitters, etc., introduces a problem.

In Figure 17-4 we show a cable only section connecting two downstream amplifiers. As the figure shows, if the transmission loss (cable only) at 220 MHz is 20 dB, then the transmission loss at 30 MHz, which would be the highest upstream transmission frequency, would be about 7.2 dB. This situation obviously dictates a 20 dB gain amplifier for downstream transmission and a 7.2 dB gain unit for upstream transmission.

In the figure in the bottom section of Figure 17-4 we have inserted two splitters, introducing 7 dB of "flat" transmission loss into the cable section. During the downstream layout process we would accommodate this additional loss by physically locating the second amplifier closer to the first unit. The cable loss downstream (at 220 MHz) would now be 13 dB as shown in the figure.

This amount of cable (13 dB at 220 MHz) would have only 4.7 dB loss at 30 MHz but the two splitters still introduce 7 dB total loss at the lower, upstream transmission frequency (30 MHz). Now the upstream amplifier must provide 11.7 dB of gain to offset the 7 dB splitting loss and the 4.7 dB cable loss, where it previously needed only 7.2 dB of gain.

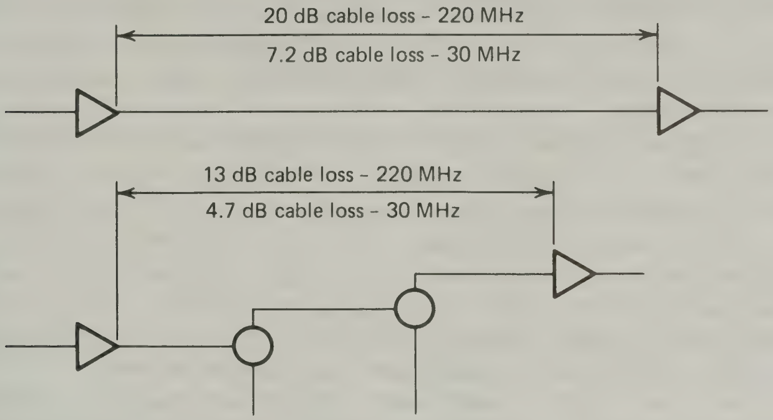

20 dB cable loss - 220 MHz
7.2 dB cable loss - 30 MHz
13 dB cable loss - 220 MHz
4.7 dB cable loss - 30 MHz

Figure 17-4 Transmission Losses

This awkward variation from upstream amplifier to upstream amplifier would be particularly evident in plant with a high incidence of flat loss insertion, such as that incurred by heavy subscriber tap loading. We must provide sufficient upstream amplifier gain to accommodate worst-case situations and then pad down amplifier inputs in less severe cable sections in order to maintain correct operational input and output levels at all upstream amplifiers. This accounts for what appears to be incongruously high gain in upstream (return) amplifier modules and is associated with frequent padding down of amplifier input levels. In effect, since upstream amplifiers must conform to downstream layout and amplifier spacings, we must use input pads in the upstream system if we are to maintain identical operating levels at all upstream amplifiers.

Using Alternate Upstream Amplifiers

Since the cable losses for the upstream system are so much lower than those for downstream transmissions, we might consider reamplifying the upstream signals only at every alternate downstream amplifier location. This would reduce dramatically the number of upstream amplifiers that are required, as well as reduce the noise and intermod contributions. This is theoretically possible and in some situations may even be practical, but there are valid arguments not to do so.

If we equip only alternate locations with upstream gain, then the signal level variations encountered along the upstream system will be greater, that is, the distance between amplifiers is greater and thus the difference between return amplifier output and input levels will be greater also. We anticipate a large number of signal origination points will be involved, in fact, we expect every subscriber station to be capable of originating an individual signal back to the head end. If the return amplifier spacings are increased by eliminating alternate amplifiers, then the output level required of the equipment at all these subscriber station signal injection points might be quite a bit higher and we may need to initiate some complex or costly output level adjustment process in such units also.

If system operation requires return transmission from only three or four discrete locations then there is a persuasive argument for alternate location upstream amplifiers. The problem of producing compatible signal outputs at only a few locations is acceptable. This situation might be encountered when just a few public schools on a system actually originate all the return signals, for example. We could adjust each transmitter individually at each of these limited locations so as to hit the input of the first return amplifier that they encounter, exactly right. It might be a bit of a nuisance but it would certainly be possible since only a few such locations are involved.

If, on the other hand, a great many stations are going to introduce upstream signals, as is the case if all subscriber terminals become two-way interactive, then the problem of compatible signal levels across a wider range from many, many units of equipment is quite a different matter. Providing smaller increments of return system gain at all amplifier locations might allow all signal sources to work at a standard, compromise output level. The result might be some limited but tolerable signal variations since losses in any one cable span would be limited by the reduced amplifier spacing. The economics of a standard subscriber terminal output level with no in-field adjustment at all required might be very attractive indeed, since so many units and so many locations are involved.

Summary

The additional cost to provide two-way capability in a coaxial cable system is quite nominal when you consider the expanded potential of the system itself. There are no insurmountable technical difficulties and we can expect two-way transmission systems operations to become very common indeed. The rate of this development will perhaps depend more upon the demonstrated profitability of some of the new services rather than on any startling or innovative technical breakthrough.

Chapter 18

Powering CATV Systems

A CATV system utilizes amplifiers distributed along the coaxial cable to compensate for transmission losses within the cable and other system devices. Each amplifier is an active unit that requires some operating power input.

Periodic installation of power supplies throughout the plant provides operating power to each active amplifier, using the coaxial cable center and outer conductors as the power transmission conductors, also. Amplifiers so powered are blocked by low frequency (60 Hz) isolation circuitry from receiving power from more than one system power supply. Thus, for low frequency transmission (60 Hz), the plant is isolated into several or many relatively small sub-sections, and all amplifiers within a sub-section receive power from a single, central power supply within that sub-section.

Power Consuming System Elements

Earlier CATV systems provided only one-way transmission capability from the point of signal origination (head end) out to all subscriber stations. Subsequent technical developments now permit two-way (bi-directional) transmission throughout the system. When such capability is provided, either initially or at a later date, then some periodic reamplification of the return path signals is necessary, and the return path amplifier modules are active devices that require powering. When engineering a system for amplifier powering, it is essential that sufficient power capacity is provided at every equipment location to accommodate any power consuming units that may be added subsequently, such as return amplifier modules.

There are Automatic Control Modules and other accessory items such as status monitoring units, for example, that may be added to some or all amplifier installations, increasing the amount of operating power these installations will require. When designing the system power distribution, it is essential that sufficient power capacity to accommodate such units be provided at every equipment location.

In many systems, mainly urban applications, bridger amplifier modules are added at trunk amplifier locations to escalate transmission signal levels to create higher level feeder cable plant, and within the feeder cable plant itself, line extender type amplifiers are required to offset cable, tap, and other device losses. Both bridger and line extender amplifiers are active units that require powering.

Most generally, power is distributed to these units through the trunk amplifier installation itself and then through the feeder plant coaxial cables. When designing the system power distribution it is essential that sufficient power capacity to accommodate bridger and all line extender requirements is provided at every trunk amplifier location.

In some systems the subscriber tap units perform a number of functions other than simply distributing the transmitted signals to subscriber service drops. Some examples are taps that perform the functions of subscriber converters, and some taps are capable of descrambling previously scrambled television signals upon commands or authorization received from the system head end. Such units are individually addressable by digital signals from the head end, and many are capable of digital response back to the head end, also. Such taps are active units in the sense that they require some operating power, and in some systems this power is provided through the coaxial cable plant itself just as amplifier power is provided.

Power Requirements

The power requirements for any individual unit of equipment can be found in the equipment technical data provided by the manufacturer. It is necessary to clearly establish the maximum power that might be required at each type of installation. That is, one must include all modules that will be installed in the station ultimately even if some modules will not be installed initially, such as return amplifier modules, for example. The system power distribution design should provide adequate powering for completely loaded station installations and sufficient capacity to power all modules that the station may eventually be equipped with.

The actual power consumption of a station will depend upon various factors such as the type of station power module provided (series or switching regulating power supply, for example), the input voltage as applied to the station power module, etc. All this data is available from the equipment manufacturer.

Amplifier Module Powering

All modern amplifier modules and other active devices are transistorized or integrated circuits today. They require a relatively low DC voltage for powering, typically 24V DC. In the early days of CATV development attempts were made to use Direct Current over the coaxial cables to power amplifiers. Electrolysis problems with dissimilar metals in cable connectors, etc., eliminated this rather quickly. The approach used for years was to power the equipments with 30 volt Alternating Current applied over the center and outer conductors of the coaxial cables.

Later, for economic reasons, coaxial cables using copper clad aluminum center conductors were introduced to replace solid copper center conductor cables. The inherent resistance of copper clad aluminum center conductors was higher of course, and the voltage drop introduced was such that 60 volt (60 Hz AC) operation was developed. This is the technique used almost universally in CATV systems today. To improve the efficiency of power transmission however, a modified square wave rather than a sinusoidal 60 Hz voltage is often employed.

Then every device inserted into the coaxial cable anywhere in the system actually must provide two independent transmission paths through it. One is for RF energy, which we will qualify as being signals above 5 MHz in frequency, and the second is a low frequency path to handle the 60 Hz energy. In any device the low frequency path can be interrupted without affecting RF transmission at all. Thus it is a simple matter to isolate sections of the system for low frequency transmission (60 Hz) with no effect at all on the RF transmission through that system. Sections of a system not requiring any power at all can be isolated for 60 Hz also.

Note that although the above discussion identifies all coaxial plant as providing two discrete transmission paths, one for RF frequencies and one for low frequency (60 Hz), in some systems the RF transmission spectrum may be further divided into two bands with one functioning for transmissions in one direction and the second for transmissions in the opposite direction. When 60 Hz energy is present in a coaxial cable, the terminations that are necessary at ends of the cable must be AC blocking, that is, they cannot be simply resistive terminations.

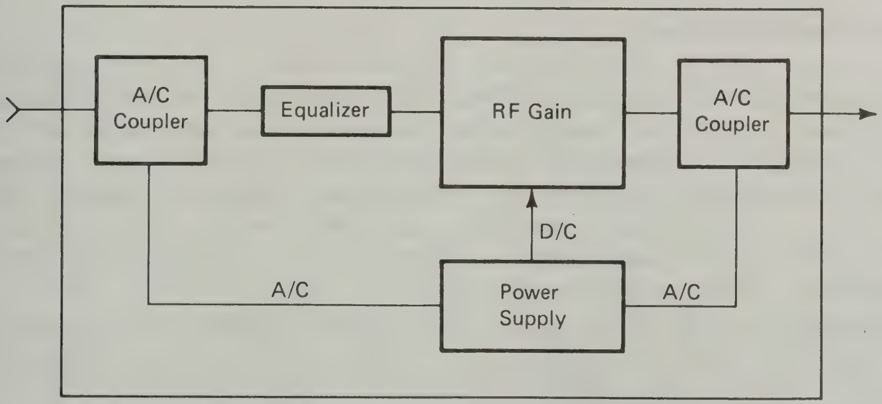


Figure 18-1 Power Bypass

In Figure 18-1 we show 60 Hz power applied to a section of coaxial cable that includes an amplifier. The 60 Hz bypass capability of the amplifier is shown in block diagram level. As shown in the figure, any 60 Hz transmission path may be individually interrupted without altering the RF transmission characteristics of the unit.

System Power Supplies

The system power supplies are located periodically throughout the plant as required. They accept an input of 117 volt AC commercial power and output 60 Hz, 60 volt power, usually in the form of a modified square wave. Such power supplies include a variety of regulating, over voltage, and current limiting features to accommodate surges on the commercial power line from which they are fed. Lightning arresters are commonly provided and various back-up capabilities, through the use of batteries and battery chargers, are available to improve system reliability.

Earlier philosophy in CATV systems did not include back-up powering of this nature on the assumption that if commercial power was out, the subscribers TV sets would be inoperative also. The fallacy of this reasoning is that commercial power may be interrupted in only a small section of the community, but if that interruption shuts down the CATV system by removing operating power in only a small section of the system, everyone beyond that point would have a functioning TV set but would not receive any input signals at all. As we add other non-TV services such as load management, alarms, data transmission, etc., the reliability of the system becomes more significant also.

Amplifier Power Modules

The power module at each amplifier installation accepts 60 Hz AC input above some threshold voltage level, usually 40 volts or so in a 60 volt system, and rectifies the AC to produce a regulated and filtered DC voltage, usually 24 volts, for operation of all the active modules located in the station. Power modules are generally protected with a fuse or circuit breaker, and often gas tube arrestor type protection is also provided on the coaxial cable center conductor to protect against voltage surges from lightning or other system irregularities.

Depending upon the design and type of a power module, there is some 60 Hz input voltage level below which the unit will drop out of regulation. When the input voltage level is below this regulating threshold, the amplifier modules may no longer perform within their specifications, and end-of-system transmission quality may be compromised.

System Voltage Drop

As we are applying the 60 Hz power to the coaxial cable, using center and outer conductors to transport 60 Hz power some distance along the cable, the resistance of both conductors becomes a factor in power distribution design.

Basic Ohm's law applies. If a finite amount of current is passed through a circuit with a finite DC resistance, then a drop in voltage will result. In Figure 18-2 we show 10 volts applied across a 20 ohm resistor. Applying Ohm's Law as shown, the current flow through the resistor will be 0.5 amperes.

$$I = \frac{E}{R}$$

$$= \frac{10}{20}$$

$$= .5 \text{ amperes}$$

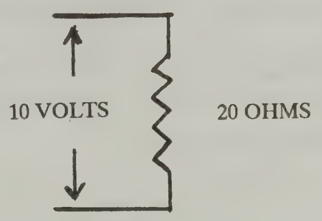


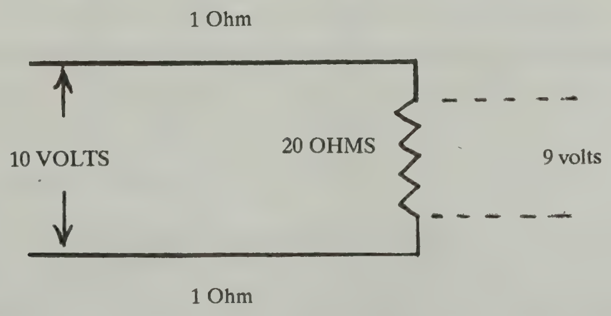
Figure 18-2 Ohm's Law

The figure ignores the interconnecting lead resistance between the load resistor (20 ohms) and the 10 volt source. Consider the same load separated some distance from the source, with interconnecting leads which have 1 ohm of resistance each, as shown in Figure 18-3.

$$I = \frac{E}{R}$$

$$= \frac{10}{22}$$

$$= .45 \text{ amperes}$$



$$E = I \times R$$

$$= 4.5 \times 2$$

$$= 9 \text{ volts}$$

Figure 18-3 Voltage Drop

The total circuit resistance is now 22 ohms as shown in the figure, and will now draw 0.454 amperes, as calculated. If 0.45 amperes flows through 2 ohms of interconnecting lead resistance, the voltage drop through the interconnecting leads will be:

$$E = I \times R$$

$$= 0.45 \times 2$$

$$= 0.9 \text{ volts}$$

where E = Voltage (volts)
I = Current (amperes)
R = Resistance (ohms)

Then the voltage actually applied across the load (resistor of 20 ohms) will be the source voltage of 10 volts less the 0.9 volt drop, or 9.1 volts. Then the current flow through the 20 ohm resistor will be:

$$I = \frac{E}{R} = \frac{9.1}{20} = 0.45 \text{ amperes}$$

This, of course, is to be expected. The condition shown in Figure 18-3 is directly analogous to the problems we face in cable systems except that the cable system will have several loads, all separated by some significant cable length, and each length with it's own significant DC resistance.

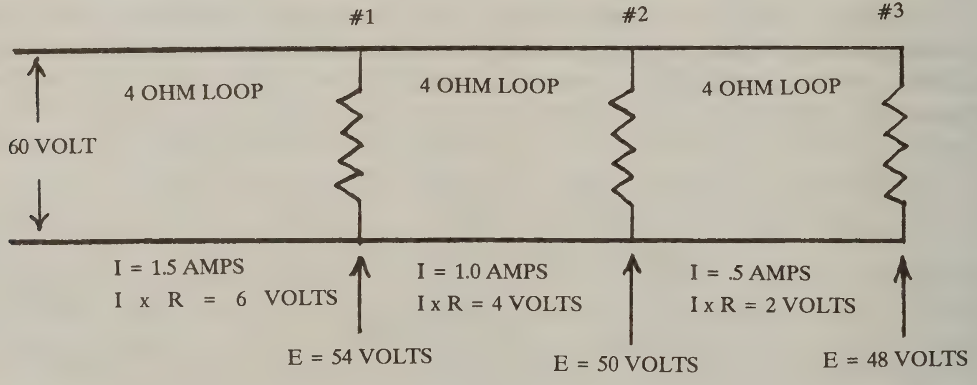

#1
#2
#3
4 OHM LOOP
4 OHM LOOP
4 OHM LOOP
60 VOLT
I = 1.5 AMPS
I x R = 6 VOLTS
I = 1.0 AMPS
I x R = 4 VOLTS
I = .5 AMPS
I x R = 2 VOLTS
E = 54 VOLTS
E = 50 VOLTS
E = 48 VOLTS

Figure 18-4 Network Voltage Drop

In Figure 18-4 we show three circuit loads representing three CATV amplifier stations, with each load separated by 2,000 feet of coaxial cable.

Let's assume that each load draws 0.500 amperes if the input voltage across it is 40 volts or higher. If the coaxial cable had 0.4 ohms resistance in the outer conductor per 1,000 feet of cable, then the outer conductor resistance between each load would be 0.8 ohms. If the center conductor had 1.6 ohms resistance per 1,000 feet of cable, then the center conductor resistance between each load would be 3.2 ohms. The operating current must flow through both the outer and center conductors as a complete circuit, thus the loop resistance between loads would be the sum of the center conductor resistance (3.2 ohms) and the outer conductor resistance (0.8 ohms), or 4.0 ohms.

Let's assume the source voltage to the network was 60 volts, as shown in the figure. If each load actually draws 0.500 amperes, then 1.5 amperes is flowing through the cable conductors connecting the power source with amplifier Number 1. Given a loop resistance in this cable of 4.0 ohms and drawing 1.5 amperes, the voltage drop through this first section of interconnecting cable would be:

$$E = I \times R = 1.5 \times 4.0 = 6.0 \text{ volts}$$

Then the voltage applied across load Number 1 is the 60 volt source voltage less the 6 volt voltage drop in the cable, leaving 54 volts applied across amplifier Number 1. Since the unit power module was specified to be able to accept 40 to 60 volts and still produce a regulated 24 volt DC output, this is acceptable.

Now let's consider the interconnecting cable between amplifiers Number 1 and Number 2. The loop resistance is the same as in the previous case (4.0 ohms) but now only 1.0 ampere is flowing, which is the total current drawn by both amplifiers Number 2 and Number 3. The voltage drop between amplifier Number 1, which may now be considered as the voltage source for the remainder of the network consisting of amplifiers Number 2 and Number 3, and amplifier Number 2 is:

$$E = I \times R = 1.0 \times 4.0 = 4.0 \text{ volts}$$

Then the voltage applied across amplifier Number 2 is the source voltage of 54 volts less 4.0 volts, or 50.0 volts. This represents the source voltage to the cable serving amplifier Number 3, the remaining portion of the network. Again the loop resistance of this cable is 4.0 ohms but the only current flowing now is the 0.500 amperes drawn by amplifier Number 3. Then the voltage drop is:

$$E = I \times R = 0.5 \times 4.0 = 2.0 \text{ volts}$$

The voltage applied across load Number 3 then will be 50.0 volts less the 2.0 volts of IR drop in the cable, leaving 48.0 volts across amplifier Number 3. By specification all three loads will provide 24 volt DC regulated output given a 40 volt AC input or higher. We had AC input to all loads of 54.0 volts, 50.0 volts, and 48.0 volts respectively, so all loads, which were CATV amplifiers in this case, will operate satisfactorily.

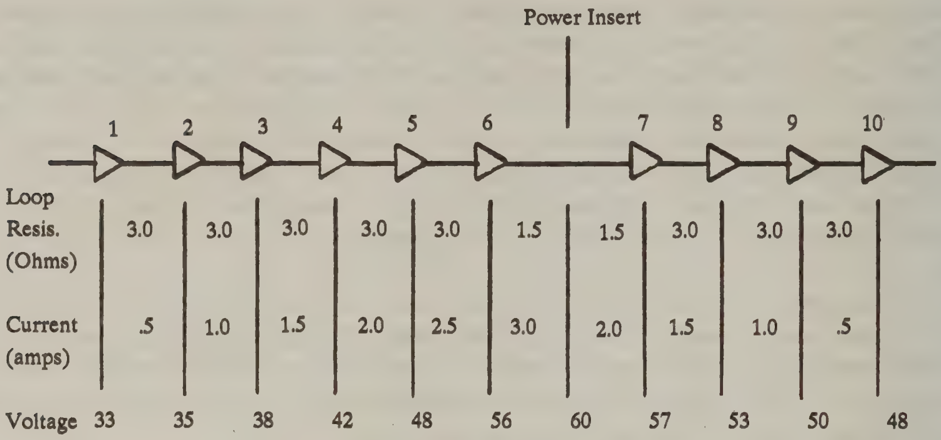


Figure 18-5 Incorrect Power Feed Location

For our example we used nice round figures, but let's examine Figure 18-5. Here we show ten stations. We assume the loop resistance between all stations is 3 ohms. Let's examine what happens if we try to locate the system power supply midpoint between stations 6 and 7. Power source output voltage is taken to be 60 volts AC with a 12 ampere capacity.

The total current drain of stations 7, 8, 9 and 10 is 2 amperes as shown in the figure. Then 2 amperes flows from the power supply to station 7 through 1.5 ohms of loop resistance as shown. The resultant IR drop is 3 volts making the voltage applied across station 7 57.0 volts. We won't show the calculations but the applied voltage to stations 8, 9, and 10 are shown, with the worst case at station 10 being an acceptable 48.0 volts AC.

In the other direction the current flow from the power supply to station 6 is 3.0 amperes through 1.5 ohms. Then the IR drop is 4.5 volts producing 55.5 volts across station 6. The subsequent operating voltages for stations 1 through 5 are as shown. Note that stations 1 through 3 are presented with less than 40.0 volts, and by equipment specifications, cannot operate properly and provide a regulated DC output at the required level.

If we relocate the power supply midway between stations 5 and 6 as shown in Figure 18-6, the individual station applied voltages are as shown. These are all acceptable voltage levels based upon the previous premise that the units will function properly with an input voltage of 40 volts or higher. Note that in both Figure 18-5 and Figure 18-6 the total current drain of all ten stations is only 5 amps. With a system power supply capability of 12 amperes we were certainly not current limited, but we did have insufficient operating voltage at 3 stations in Figure 18-5.

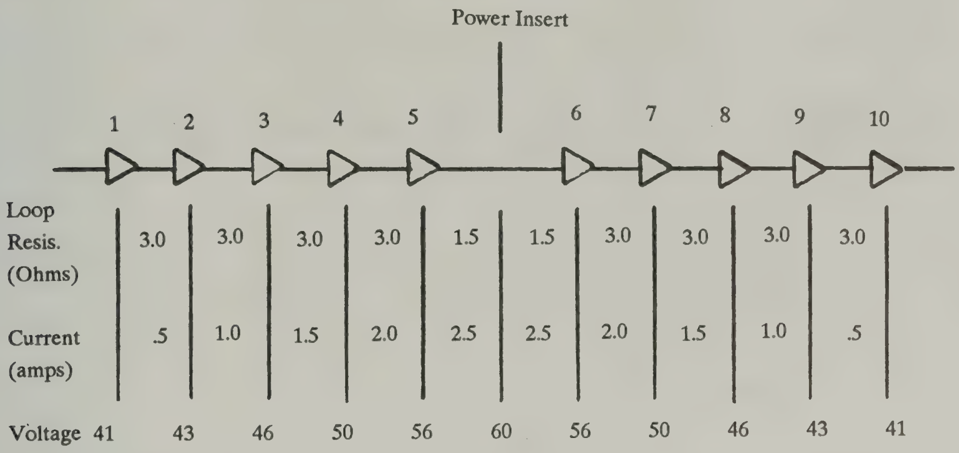


Figure 18-6 Correct Power Feed Location

And in Figure 18-6 we had no remaining margin to power any stations beyond 1 and 10. We were voltage limited in this case due to the long amplifier spacings and the IR drop in the long interconnecting cable runs.

This condition of voltage limiting may be commonly experienced in rural systems using higher gain amplifiers and relatively long physical spacing between amplifiers. In such instances the power supply may be unavoidably inefficiently used since it's capacity (12 amps) could not be fully utilized. It is often difficult to power a long, wide spaced system efficiently for these reasons.

Example Trunk Plus Feeder Design

Examine Figure 18-7 which shows a small section of a trunk plus feeder system. We show three combination trunk/bridger stations with two feeder amplifiers (line extenders) powered from each trunk station. We will assume each trunk station will draw 0.6 amperes and each feeder station 0.4 amperes. We will also assume that the manufacturer's specifications on this equipment states that every amplifier must be fed a minimum AC input voltage of 40 volts.

The question to be resolved is where can we locate the 117 volt AC system power supply to feed this section of system.

We start the design process by powering the most distant amplifier correctly, and in this drawing this would be the line extender amplifier in the upper right hand corner of the drawing. The manufacturer's specifications tell us this unit must be provided with an input voltage no lower than 40 volts. We notate this on Figure 18-8.

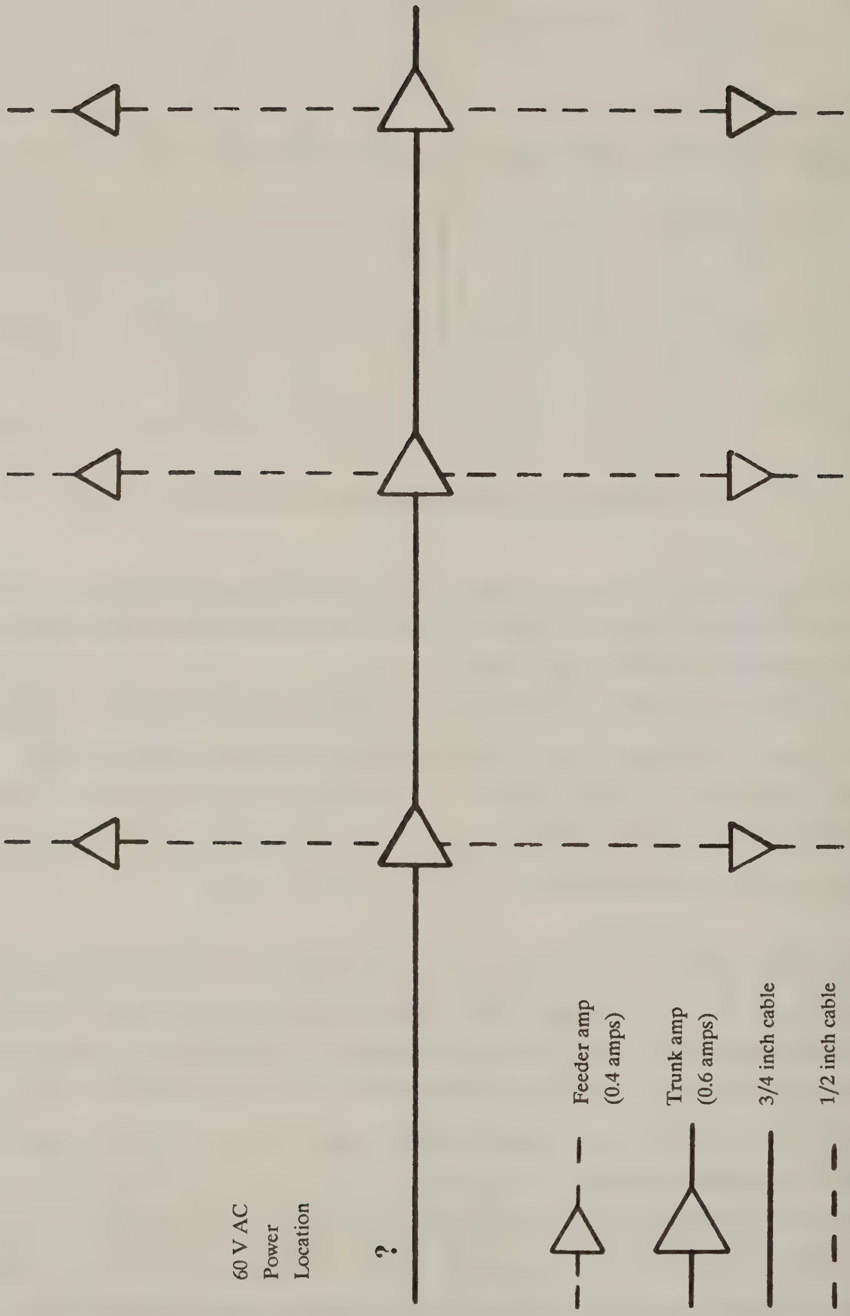

60 V AC
Power
Location
?
Feeder amp
(0.4 amps)
Trunk amp
(0.6 amps)
3/4 inch cable
1/2 inch cable

Figure 18-7 System Powering Example

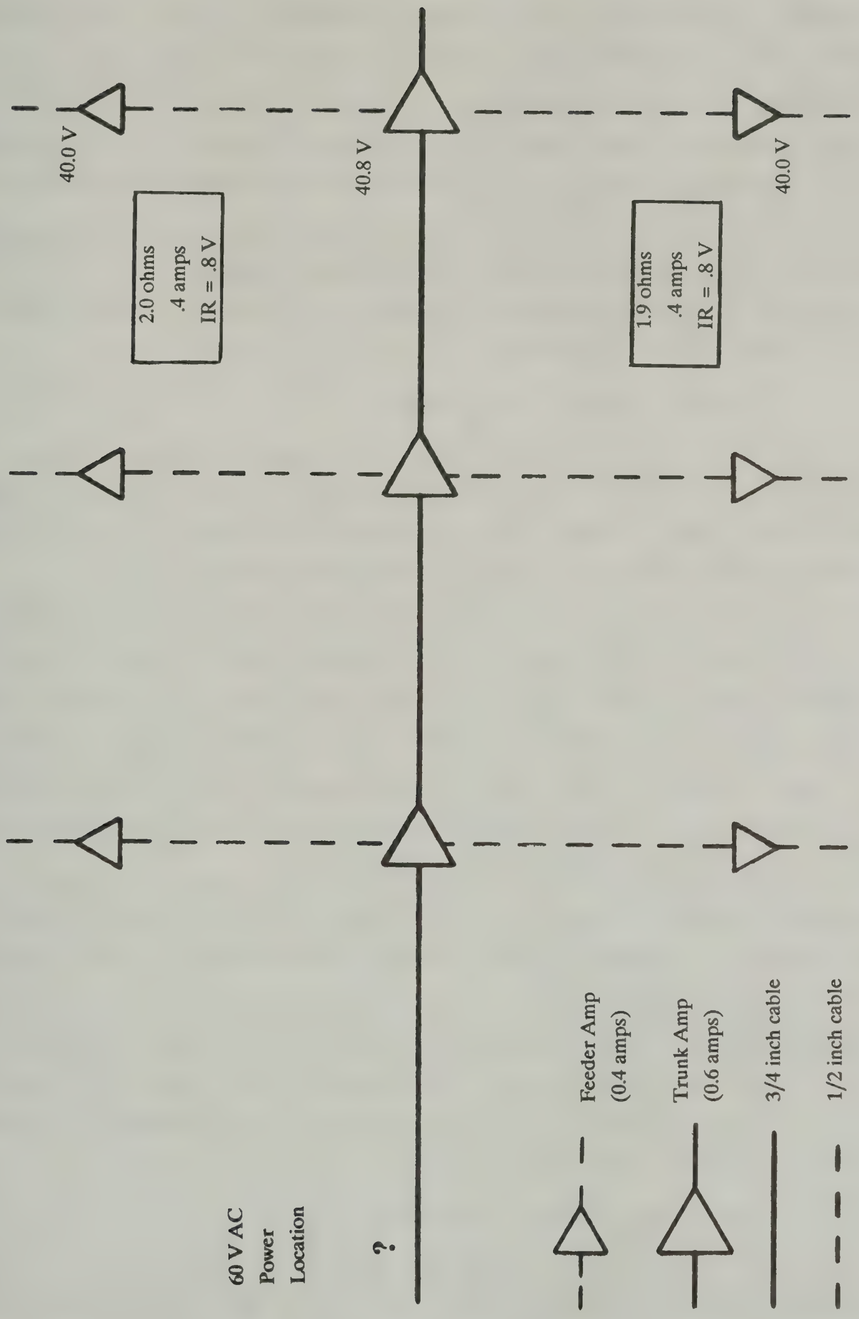

60 V AC
Power
Location
?
2.0 ohms
.4 amps
IR = .8 V
40.0 V
40.8 V
40.0 V
1.9 ohms
.4 amps
IR = .8 V
Feeder Amp
(0.4 amps)
Trunk Amp
(0.6 amps)
3/4 inch cable
1/2 inch cable

Figure 18-8 System Powering Example

The amplifier locations were all previously established by the RF transmission design process. From the system layout drawings we can easily determine what length of .500 inch cable is in place connecting our line extender to the trunk/bridger unit that feeds it. From the cable manufacturer's specification sheet we can easily determine the loop resistance (inner plus outer conductor resistance) for this length of cable. We find this loop resistance to be 2.0 ohms and we have entered this on the drawing inside the box as shown on Figure 18-8.

We previously determined that each line extender would draw 0.4 amperes of current. We have entered this figure inside the same box in the drawing.

If a current of 0.4 amperes is passed through a resistance of 2.0 ohms, then the voltage drop introduced will be 0.8 volts from:

$$E = I \times R \quad = 0.4 \times 2 \quad = 0.8 \text{ volts}$$

Since we know we need a minimum of 40 volts applied across the amplifier, and we know we will incur an 0.8 voltage drop through the interconnecting cable, it follows that we must apply at least 40.8 volts across the network at the point where the trunk/bridger amplifier is located. We notate this voltage on Figure 18-8.

We can now take a quick look at the other feeder amplifier fed from this trunk location in order to make certain it will receive at least 40 volts, as required. We note the length of the cable from the system design drawings and establish the loop resistance for .500 inch cable of this length. We entered that figure, 1.9 ohms, in the box on the drawing. We know this amplifier will also draw 0.4 amperes and we entered this figure also. The voltage drop in this cable is 1.9 x 0.4 = .76 volts, which we round off to 0.8 volts. Then a voltage of 40.8 volts applied across the trunk/bridger unit would ensure 40 volts across each of the line extender amplifiers. We can proceed in the design effort to ensure 40.8 volts at this point in the trunk plant.

From the layout drawings we can determine the cable footage between the last two trunk/bridger amplifiers in Figure 18-9. We note that this is .750 inch cable and we determine the loop resistance of such a length of this cable. We enter this figure, 2.0 ohms, in the new box in Figure 18-9.

Since we will be feeding two line extenders which draw 0.4 amperes each, plus one trunk/bridger amplifier which draws 0.6 amperes, we add these together to determine that 1.4 amperes will flow through this section of the system. We enter this figure in the new box in Figure 18-9. With 1.4 amperes flowing through 2.0 ohms, the voltage drop through this interconnecting cable will be:

$$E = I \times R \quad = 1.4 \times 2 \quad = 2.8 \text{ volts}$$

If we require at least 40.8 volts across the last trunk amplifier, as we determined and notated earlier, then we will require 43.6 volts across the preceding trunk unit to accommodate this 2.8 volts of drop and still produce 40.8 volts at the required point. We note this figure, 43.6 volts, in Figure 18-9.

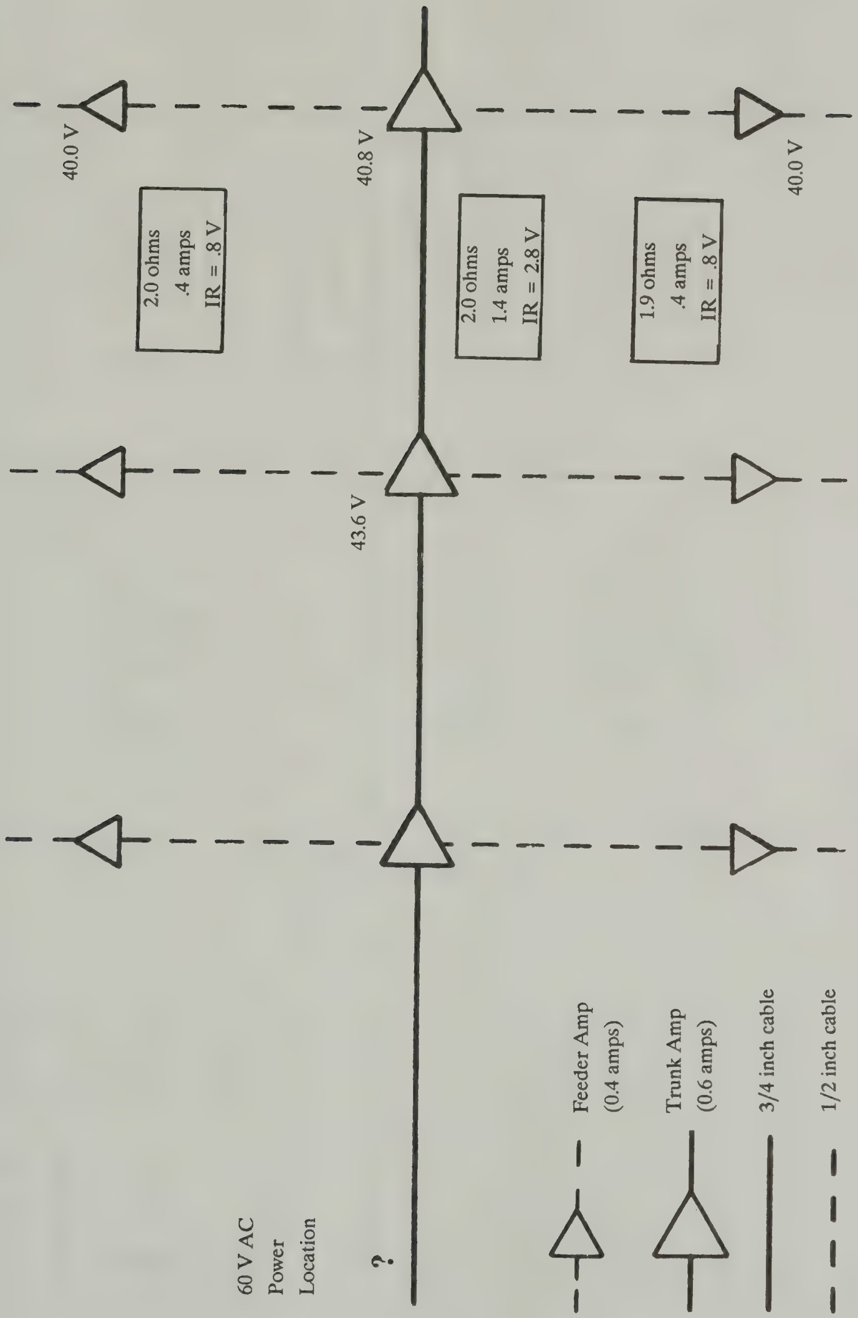

40.0 V
40.8 V
40.0 V
2.0 ohms
.4 amps
IR = .8 V
2.0 ohms
1.4 amps
IR = 2.8 V
1.9 ohms
.4 amps
IR = .8 V
43.6 V
60 V AC
Power
Location
?
Feeder Amp
(0.4 amps)
Trunk Amp
(0.6 amps)
3/4 inch cable
1/2 inch cable

Figure 18-9 System Powering Example

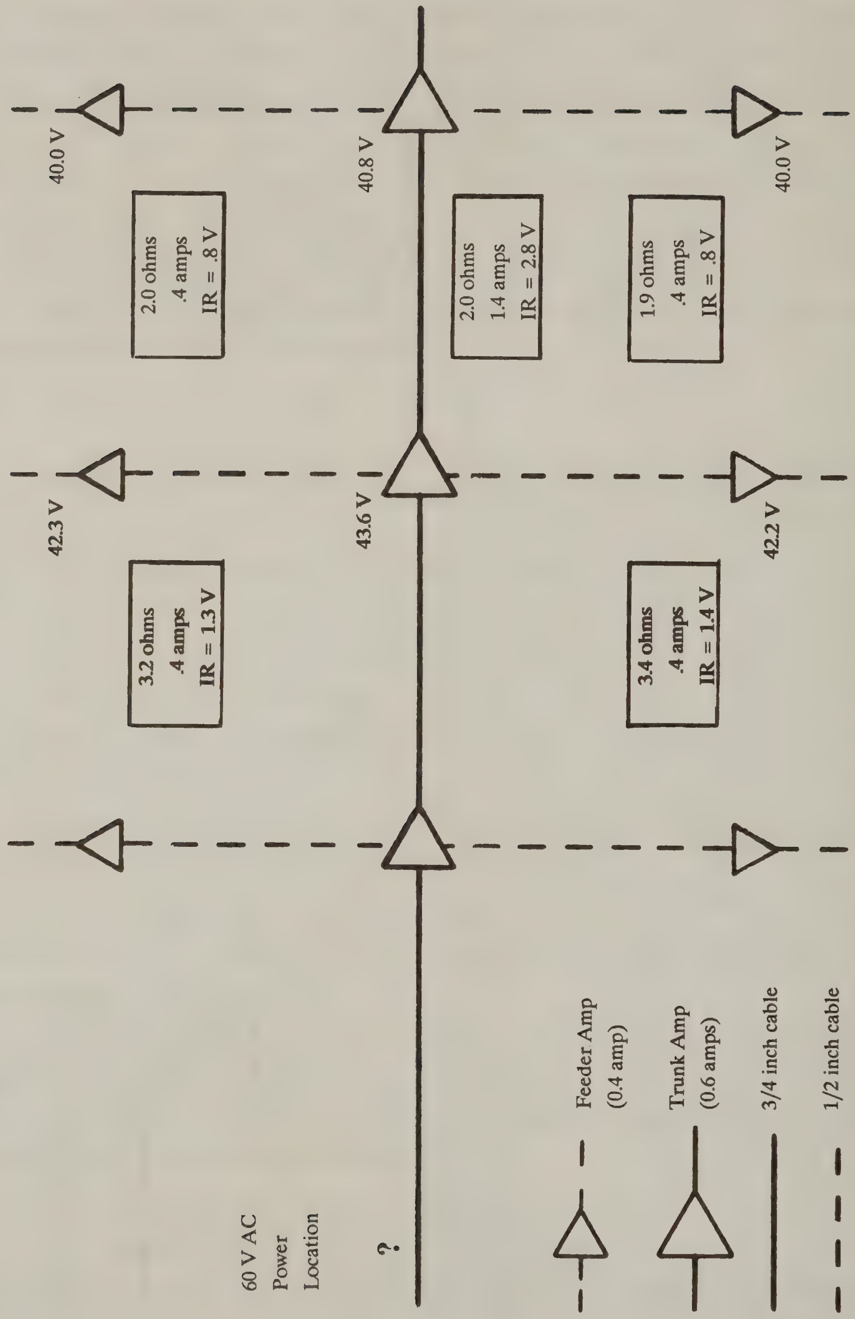

60 V AC
Power
Location
?
Feeder Amp
(0.4 amp)
Trunk Amp
(0.6 amps)
3/4 inch cable
1/2 inch cable
42.3 V
3.2 ohms
.4 amps
IR = 1.3 V
43.6 V
3.4 ohms
.4 amps
IR = 1.4 V
42.2 V
40.0 V
2.0 ohms
.4 amps
IR = .8 V
40.8 V
2.0 ohms
1.4 amps
IR = 2.8 V
1.9 ohms
.4 amps
IR = .8 V
40.0 V

Figure 18-10 System Powering Example

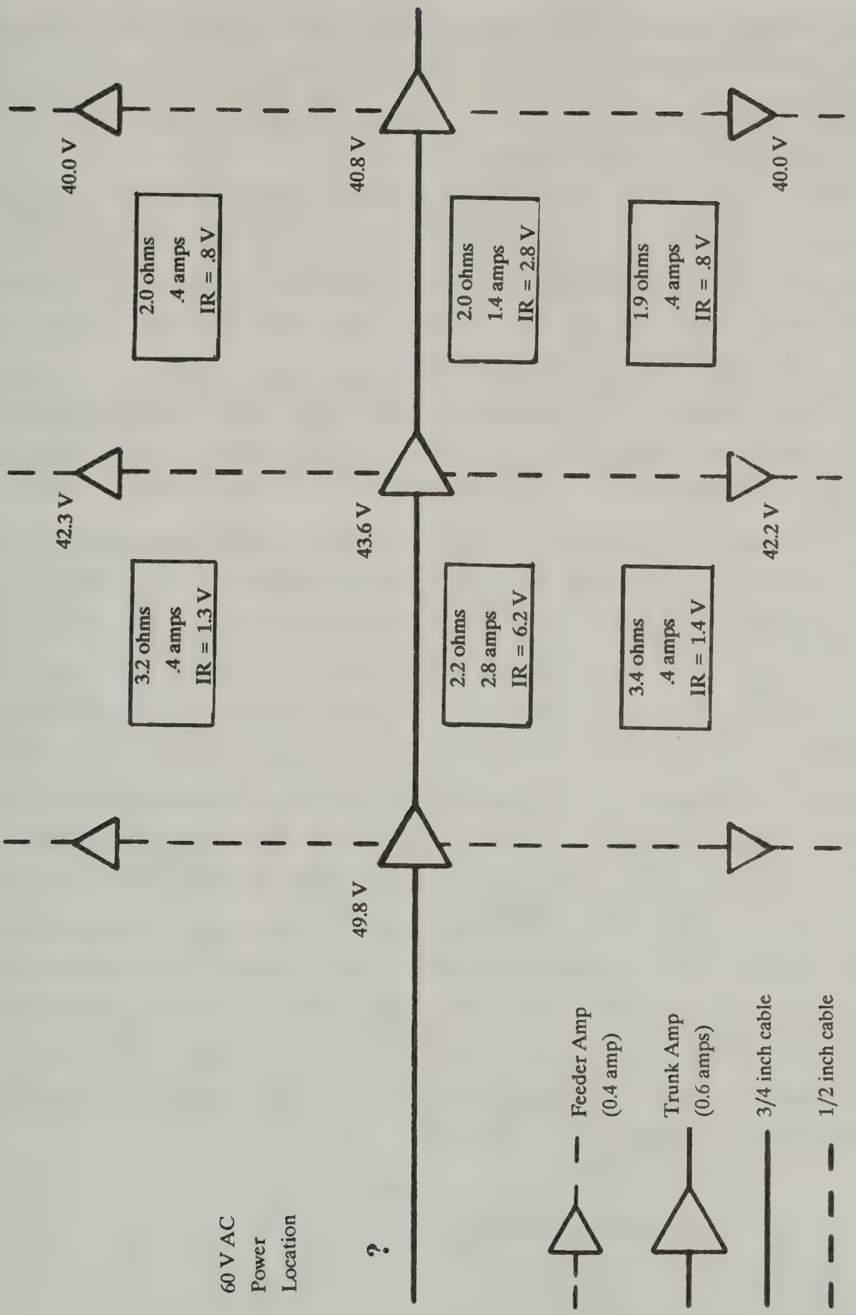

60 V AC
Power
Location
?
49.8 V
43.6 V
40.8 V
42.3 V
40.0 V
42.2 V
40.0 V
3.2 ohms
.4 amps
IR = 1.3 V
2.2 ohms
2.8 amps
IR = 6.2 V
3.4 ohms
.4 amps
IR = 1.4 V
2.0 ohms
.4 amps
IR = .8 V
2.0 ohms
1.4 amps
IR = 2.8 V
1.9 ohms
.4 amps
IR = .8 V
Feeder Amp
(0.4 amp)
Trunk Amp
(0.6 amps)
3/4 inch cable
1/2 inch cable

Figure 18-11 System Powering Example

We can easily verify if this voltage, 43.6 volts, applied across this point, can adequately handle both the line extender amplifiers served by this point. In the new boxes in Figure 18-10 we show a 1.3 and 1.4 voltage drop respectively, providing 42.3 volts and 42.2 volts across these two units. This is fully compliant with the requirements so we can proceed with the design process.

In Figure 18-11 we have added a box indicating a loop resistance of 2.2 ohms for the next section of .750 inch trunk cable. This was determined by the amplifier spacing on the RF system layout drawings. Note that we show in this new box a current flow of 2.8 amperes. This was established by the fact that past this point we are feeding two trunk/bridger units drawing 0.6 amperes each, plus four line extender amplifiers drawing 0.4 amperes each. This totals 2.8 amperes.

The voltage drop through this section of trunk cable will be E = I x R, or 2.8 x 2.2 = 6.12 volts, which we will round off to 6.2 volts. Quite obviously we must apply 49.8 volts across the network at this point if we are to absorb a 6.2 voltage drop and still produce the required 43.6 volts across the next amplifier. We notated this in Figure 18-11.

We are sufficiently experienced now to make a quick judgement that 49.8 volts across the network at this point will easily accommodate both line extender amplifiers fed from this point, but just to reinforce our understanding, we can quickly review the boxes that have been added to Figure 18-12 to show loop resistance, current flow, and consequent voltage drop. We can see at a glance in Figure 18-12, that both line extenders receive voltage well above the specified minimum of 40 volts even though one of these is fed through a fairly long cable run that introduces 4.1 ohms of loop resistance.

We have established that the entire network we have examined will be adequately served if we apply a potential of 49.8 volts across the first trunk/bridger amplifier. The question remains as to how far from this point we can locate the system AC power supply and not compromise this figure of 49.8 volts.

If we know that our AC power supply will output 60 volts, and we know we need 49.8 volts applied across the first amplifier in the network, then we know we can accept up to a 10.2 volt drop in the cable between the AC power supply and the first amplifier. Using Ohm's Law we can determine how much loop resistance we can tolerate since we know this cable will be carrying 4.2 amperes. This current represents the total of six line extenders drawing 0.4 amps each (0.4 x 6 = 2.4 amps), plus three trunk units drawing 0.6 amps each (0.6 x 3 = 1.8 amps).

$$E = I \times R \text{ and } R = \frac{E}{I}$$

$$\text{then } R = \frac{10.2}{4.2} = 2.43 \text{ ohms}$$

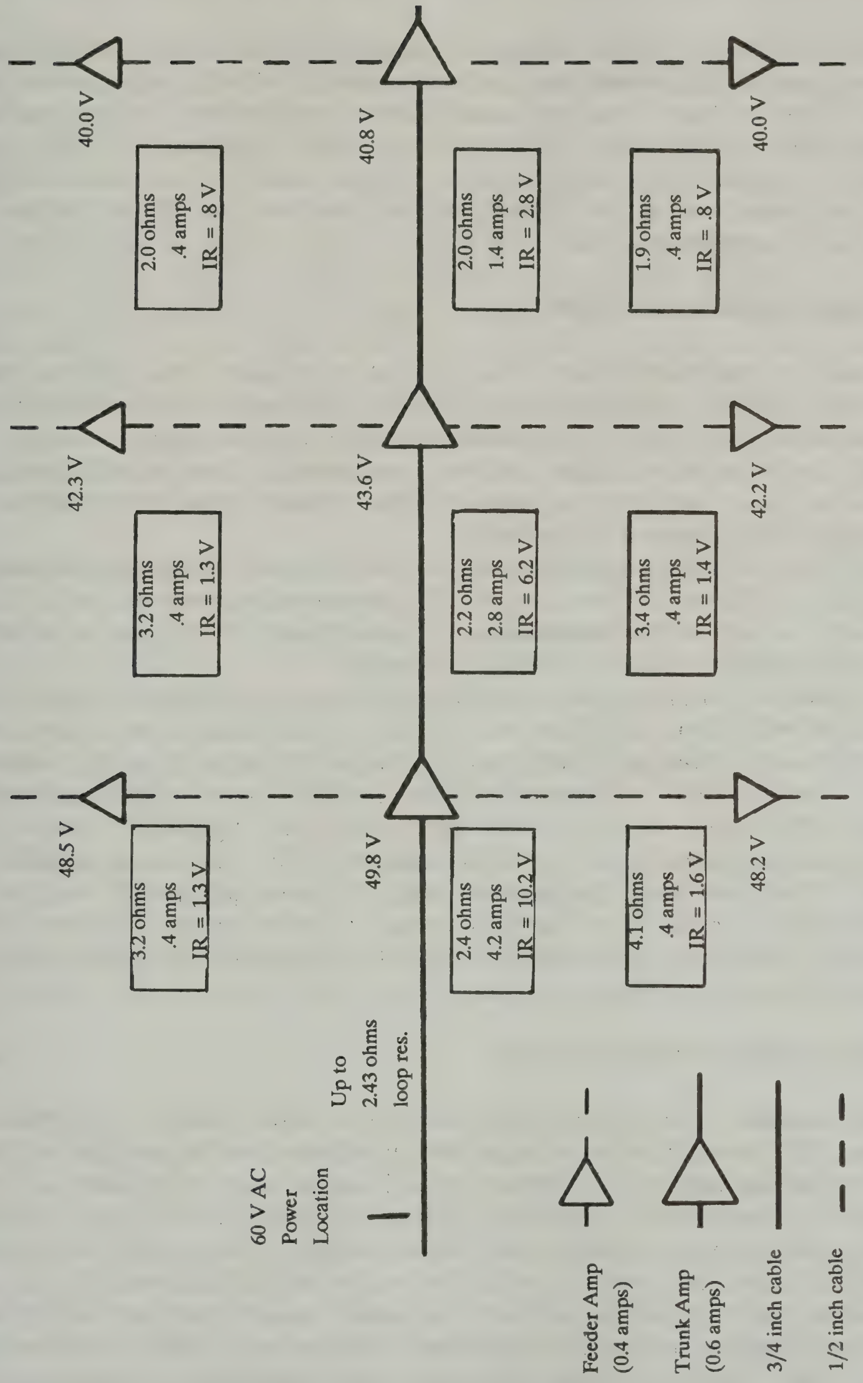

60 V AC
Power
Location
Up to
2.43 ohms
loop res.
49.8 V
2.4 ohms
4.2 amps
IR = 10.2 V
43.6 V
2.2 ohms
2.8 amps
IR = 6.2 V
40.8 V
2.0 ohms
1.4 amps
IR = 2.8 V
48.5 V
3.2 ohms
.4 amps
IR = 1.3 V
42.3 V
3.2 ohms
.4 amps
IR = 1.3 V
40.0 V
2.0 ohms
.4 amps
IR = .8 V
48.2 V
4.1 ohms
.4 amps
IR = 1.6 V
42.2 V
3.4 ohms
.4 amps
IR = 1.4 V
40.0 V
1.9 ohms
.4 amps
IR = .8 V
Feeder Amp
(0.4 amps)
Trunk Amp
(0.6 amps)
3/4 inch cable
1/2 inch cable

Figure 18-12 System Powering Example

We can locate the system AC power supply up to 2.43 ohms of cable loop resistance away and still produce the required potential of 49.8 volts across the first amplifier. Since we know from the manufacturer's specifications, the loop resistance of .750 inch cable per 100 foot of length, we can easily calculate the cable footage at which the AC power supply can be spaced. We can locate it closer than this if necessary but we cannot exceed this distance without compromising the AC voltage applied across some of the system amplifiers.

Low Voltage Amplifier Operation

It must be recognized that stations operating at lower input voltages will draw more current and this additional current flow may produce an unacceptable IR drop in some portion of the power design. Another factor is that the loop resistance of coaxial cable will be increased at higher ambient temperatures, thus in calculating network voltage drops, some consideration must be given to the temperature extremes that the cable can logically be expected to experience.

The figure we have used of 40 volts as the minimum operating voltage input for an amplifier is arbitrary and was selected for demonstration purposes only. The reader is cautioned to review the manufacturer's specifications for the particular units that may be under consideration for a particular application.

It should be noted that any amplifier will operate satisfactorily with an applied voltage of 60 volts. Some amplifiers may require a minor manual adjustment for input voltage if the input voltage is high, that is, close to 60 volts. It may be necessary to switch in some circuitry to assure that the amplifier power supply can adequately regulate it's DC output with this level input. Thus some equipments provide a coarse switch adjustment, often called "local" or "remote." This allows the amplifier to be employed in locations where the applied voltage is lower, perhaps 50 volts and lower, or installed in a location where the input voltage is higher, perhaps between 50 and 60 volts, and in either case, still produce a regulated, dependable 24 volts DC for proper operation of all station modules.

Positioning System Power Supplies

The selection of a power supply location is often dictated by physical plant conditions. For example, commercial power secondaries must be available at that pole to feed the power supply, and adequate pole clearance must be available for mounting the unit, etc. In practice, a tentative location is marked on the pole line drawings after the system powering process has been completed, but a field visit is made to determine if that location is actually practical before the installation is made.

Note in our example that locating the power supply closer to the first amplifier location would present no technical problems, but locating it farther away would affect amplifier input voltages somewhat and could affect amplifier performance or service life.

There is some latitude in relocating power supplies, but it requires judgement, and sometimes an engineering review is necessary. Usually a repositioning of a pole span or two is quite acceptable.

General Discussion

Our example was a rather simple problem but the methodology is clearly shown. In practice we might expect to find more complex combinations involving many more line extenders for example, but the basic technique and technical limitations would remain the same. The power distribution design problem is tedious and time consuming and requires a series of calculations, but it is not particularly sophisticated at all. In computer assisted system designs, the power design is usually produced by the software program as the design work progresses and no special effort is required. It is still important that the engineer and system service technicians understand how power is provided to all equipment locations at the proper levels.

The factors involved that must be identified with some precision are:

1. The loop resistance of all sizes of coaxial cables involved.
2. The output voltage and current rating of AC power supplies.
3. The current drain of all types of equipment involved, including modules that may be added to the equipments at some later date.
4. The minimum input voltage requirements of all types of equipment involved, including increased current drain if lower voltages are provided.
5. Any possible system extensions that might require powering at a later date, but have been deferred as initial construction projects, for any reason.

Summary

Powering CATV plant is less complex than developing the RF transmission design itself, and although time consuming, should present no problems to the competent system designer. An inadequate power distribution design can have undesirable effects on long term operation and maintenance costs. For example, if seasonal temperature changes are not anticipated and provided for in the power design, the system may operate erratically in hot weather.

If the power design is too conservative, that is, individual power supplies are not efficiently employed, then both the initial construction cost, and the operating cost of the facility as well, may be higher than actually necessary.

Chapter 19

Coaxial Cables and Service Drops

By definition, a coaxial cable is two metallic conductors sharing the same axis, hence the terminology coaxial. In actuality this is a metallic center conductor, coaxially positioned within an outer metallic conductor with the two separated by some dielectric (nonconducting) material.

The size and type of coaxial cable employed in a system has a great deal to do with the transmission design and a significant impact on system costs as well. Any meaningful discussion of coaxial cable must consider the present state of the art of cable manufacturing and the cost of the cable. Both of these factors are subject to change, so the long-term value of any discussion here may be somewhat questionable.

But individuals involved in planning or designing CATV systems will be required to recommend or select specific cable, and some understanding of the cost differentials and technical trade-offs is essential. We will present a methodology for comparison of cable types and sizes to familiarize the reader with the relationship of costs between various sizes and types.

The cost figures used should be considered representative rather than precise. They were developed as a composite of several manufacturers' published price sheets and they do not reflect any discounts or available volume buying advantages. The relationship of prices between types and sizes of cable would, it is assumed, remain relatively constant even if price schedules changed across the entire product line.

Mechanical Considerations and Types

A wide variety of cable configurations is available for different environmental and construction requirements. Basically, all are modifications of the least complex bare aluminum cable. This is seamless aluminum tubing enclosing the center conductor and the dielectric. The next level of sophistication is this same cable enclosed in a high molecular weight polyethylene outer jacket.

A variation on this adds a "flooding" compound that provides some self-healing protection for abrasions or ruptures of the outer jacket itself. Generally, the use of jacketed cable is restricted to corrosive environments such as salt air, coastal installations, or localized, corrosive atmosphere from industrial processes, etc. Most coaxial cable placed aerially is unjacketed.

For underground installations, either direct burial or in protective underground duct systems, various levels of additional mechanical protection are provided ranging from a single jacket with flooding compound up to a metallic armor wrapping plus a second outer jacketing, also with flooding compound protection.

Coaxial cable is also available with an integral support member that eliminates the necessity for a separate, mechanically supporting "strand" or "messenger." Sometimes referred to as "self-support," "figure eight," or "integrated messenger" (IM) cables, these incorporate either a single galvanized steel support wire or stranded, galvanized steel support cable molded into a poly jacket that integrates both support messenger and coaxial cable into a single mechanical entity. Integrated cable of this type provides lower plant construction costs but inhibits the future possibility of over-lashing a second cable onto the initially constructed plant.

Cable sizes generally employed in CATV construction are 0.412 inch, etc. The cable is measured by the outside diameter (O.D.) of the outer conductor itself, not including any protective jackets or armor, are 0.412 inch, 0.500 inch, 0.625 inch, 0.750 inch, 0.875 inch, and 1 inch. Larger cables are available but are not widely used, and both copper-clad center conductor and solid copper center conductor cables can be supplied, but for economic reasons, most CATV systems employ copper-clad aluminum center conductor cables exclusively.

Electrical Considerations and Type

The electrical characteristics of interest are:

1. Capacitance
2. Impedance
3. Velocity of propagation
4. DC resistance
5. RF attenuation
6. Structural return loss

Of these characteristics, all of which manufacturers specify in catalogues and sales literature, the two most critical for system design and layout purposes are DC resistance and RF attenuation.

The DC resistance is typically specified for the center conductor alone, the outer conductor alone, and the "loop" resistance. This information along with the amplifier current drain and cable lengths in the system layout, are essential input in designing the system powering.

Locating and placing system power supplies is usually done after all amplifier layout is completed. The cable "loop" resistance is a factor in determining voltage drops throughout the plant.

RF attenuation is a function of both cable size (outside diameter) and dielectric material characteristics. For a given dielectric, the larger the cable, the lower the RF attenuation. Of course, the larger the cable size, the higher the cost.

Dielectric material ranges from solid polyethylene material to air, with a medium in between of "foamed" (gas or air entraining) expanded polyethylene material. Solid or foam dielectric materials provide continuous mechanical support and positioning for the center conductor. In air dielectric cables, the center conductor position is maintained by thermoplastic discs spaced periodically throughout the cable length.

Due to excessive transmission losses, solid dielectric cable is infrequently used in CATV systems today, and 1 inch cables and larger, although available, are intentionally limited in usage as much as possible due to their higher cost.

Economic Comparisons of Cable Types and Sizes

We emphasize that the cost data presented here may not be current but we are not developing a cost estimate here, we are merely presenting a comparison of cost-effectiveness. This comparison is somewhat theoretical in that it does not take into consideration the other factors that must be considered in the cable selection process. For example, in a large, urban, trunk-plus-feeder system, the selection of a larger size trunk cable at higher cost may be entirely justified for technical reasons rather than economics alone. Some understanding of the economics of cable selection will be useful background information, despite the variable nature of these costs, and these comparisons are presented in that context.

The following types and sizes of cable will be the subjects for comparison. In each case, the cable cost is taken for bare, unjacketed cable.

Table 19-A Cable Losses

Size (inch)	220 MHz (dB/100 ft)	300 MHz (dB/100 ft)	450 MHz (dB/100 ft).
Foam Dielectric Cables			
0.412	1.31	1.56	1.93
0.500	1.08	1.29	1.59
0.625	0.88	1.05	1.30
0.750	0.74	0.88	1.10
0.875	0.64	0.77	0.96
1.000	0.59	0.70	0.89

Size (inch)	220 MHz (dB/100 ft)	300 MHz (dB/100 ft)	450 MHz (dB/100 ft).
Air Dielectric Cables			
0.440	1.11	1.33	1.64
0.500	.95	1.14	1.40
0.650	.76	.91	1.13
0.750	.66	.79	.97
1.000	.49	.60	.74

Untapped Cable Cost Comparison

We will consider a purely hypothetical cable run of twenty miles with no subscriber taps or cable splitting at all. We will assume amplifier spacing of 31 dB for the 220-MHz application, 28 dB for 300 MHz, and 25 dB for the 450 MHz system.

Table 19-B 20 Mile Analysis - Cable Only

Size (in.)	220 MHz (loss/mile)	300 MHz (loss/mile)	450 MHz (loss/mile)	Cost (per mile)
Foam Dielectric Cables				
0.412	69.2	82.4	101.9	$ 982
0.500	57.0	68.1	84.0	$ 1,298
0.625	46.5	55.4	68.6	$ 2,022
0.750	39.1	46.5	58.1	$ 2,719
0.875	33.8	40.7	50.1	$ 3,806
1.000	31.2	37.0	47.0	$ 5,047
Air Dielectric Cables				
0.440	58.6	70.2	86.6	$ 1,314
0.500	50.2	60.2	73.9	$ 1,531
0.650	40.1	48.0	59.7	$ 2,360
0.750	34.8	41.7	51.2	$ 3,342
1.000	25.9	31.7	39.1	$ 7,122

Although we do not present a development for higher frequency (500 or 550 MHz, for example) the interested reader can follow the methodology used and develop an analysis, and is encouraged to do so. We will apply an arbitrary $900 amplifier cost for each case, and the reader should recognize that this arbitrary figure may differ substantially from actual equipment cost.

From Table 19-B we can extract the total cable loss in a 20 mile cable route, divide by the usable amplifier gain (spacing), and then cost in both cable and amplifiers to produce a cost per mile for comparison purposes. Some economic weight should be given to alternatives that employ fewer amplifiers to reflect the long-term operation and maintenance costs of the amplifiers themselves. Suppose we arbitrarily assume an annual cost of 15 percent of initial cost per amplifier. Then each $900 unit would be considered to represent an annual, recurring cost of $135 to operate and maintain. We will use this figure in any comparisons of cost as a factor in the decision making process. The reader is free to apply any other figure that operating experience may dictate to be more accurate.

We can now examine the tabulated data for some indication of cost-effectiveness. For example, Table 19-F shows a cost per mile of $ 3,609 using 0.440 inch air dielectric cable. But Table 19-E shows that this alternative requires a total of 50 amplifiers. If we were comparing this particular alternative to 0.500 inch air dielectric cable, we would find this cost to be $3,466 per mile but requiring only 43 amplifiers. This is 7 amplifiers fewer, and at an arbitrary $135 annual cost per amplifier, the 0.500 inch air cable would produce an annual cost reduction of 135 x 7 or $945 per year. This factor might enter into the decision-making process.

An analysis of this type is not simply theoretical. In an extended super-trunk cable run, the methodology presented might be very appropriate. The tabulated data also gives some feel for the economic impact of higher system transmission frequencies. For example, comparing 0.500 inch air dielectric cable for both 220 and 450 MHz applications, we find the cost at the higher frequency to be $1,215 per mile higher, a penalty of about 40 percent of the lower frequency per mile cost. If we examine the data we will find the .500 size cable is the most economical in every case. We can even compare air dielectric with foam dielectric. For example at 220 MHz, .500 inch foam is slightly more economical than either .440 or .500 air cable, but at 300 and 450 MHz, .500 air cable is the least expensive of all. However, .500 foam cable is more economical than the .440 air cable at both 300 and 450 MHz.

Of course this data must be analyzed with some regard to the other factors involved. For example, the .500 foam cable requires significantly more amplifiers than the air dielectric cables do. The reader is encouraged to browse through the above data simply to reinforce his or her understanding of the economics of the different types and sizes of cable that are available. Note that all this data is for a 20 mile length of cable with no subscriber tapping at all.

Table 19-C 20 Mile Route - 220 MHz

Cable Size (inch)	Dielectric Material	Total Loss (20 miles)	Amplifiers Req'd. (total)	(per mile)
0.412	Foam	1384	44.6	2.2
0.500	Foam	1140	36.8	1.8
0.625	Foam	930	30.0	1.5
0.750	Foam	782	25.2	1.3
0.875	Foam	675	21.8	1.1
1.000	Foam	624	20.1	1.0
0.440	Air	1172	37.8	1.9
0.500	Air	1004	32.4	1.6
0.650	Air	802	25.9	1.3
0.750	Air	696	22.5	1.2
1.000	Air	518	16.7	0.8

Table 19-D 20 Mile Route Cost - 220 MHz

Size (inch)	Dielectric Material	Cable Cost	Amp. Cost	Total Cost	Cost (per mile)
0.412	Foam	19,640	40,500	60,140	$ 3,007
0.500	Foam	25,960	33,300	59,260	$ 2,963
0.625	Foam	40,440	27,000	67,440	$ 3,372
0.750	Foam	54,380	23,400	77,780	$ 3,889
0.875	Foam	76,120	19,800	95,920	$ 4,796
1.000	Foam	100,940	18,900	119,840	$ 5,992
0.440	Air	26,280	34,200	60,480	$ 3,024
0.500	Air	30,620	29,700	60,320	$ 3,016
0.650	Air	47,200	23,400	70,600	$ 3,530
0.750	Air	66,840	20,700	87,540	$ 4,337
1.000	Air	142,440	15,300	157,740	$ 7,887

Table 19-E 20 Mile Route - 300 MHz

Cable Size (inch)	Dielectric Material	Total Loss (20 miles)	Amplifiers Req'd. (total)	(per mile)
0.412	Foam	1384	58.9	2.9
0.500	Foam	1140	48.6	2.4
0.625	Foam	930	39.6	2.0
0.750	Foam	782	33.2	1.7
0.875	Foam	675	29.1	1.5
1.000	Foam	624	26.4	1.3
0.440	Air	1172	50.1	2.5
0.500	Air	1004	43.0	2.2
0.650	Air	802	34.3	1.7
0.750	Air	696	29.8	1.5
1.000	Air	518	22.6	1.1

Table 19-F 20 Mile Route Cost - 300 MHz

Size (inch)	Dielectric Material	Cable Cost	Amp. Cost	Total Cost	Cost (per mile)
0.412	Foam	19,640	53,100	72,740	$ 3,637
0.500	Foam	25,960	44,100	70,060	$ 3,503
0.625	Foam	40,440	36,000	76,440	$ 3,822
0.750	Foam	54,380	30,600	84,980	$ 4,249
0.875	Foam	76,120	27,000	102,120	$ 5,156
1.000	Foam	100,940	24,300	125,240	$ 6,262
0.440	Air	26,280	45,900	72,180	$ 3,609
0.500	Air	30,620	38,700	69,320	$ 3,466
0.650	Air	47,200	31,500	78,700	$ 3,935
0.750	Air	66,840	27,000	93,840	$ 4,692
1.000	Air	142,440	20,700	163,140	$ 8,157

Table 19-G 20 Mile Route - 450 MHz

Cable Size (inch)	Dielectric Material	Total Loss (20 miles)	Amplifiers Req'd. (total)	(per mile)
0.412	Foam	1384	81.5	4.1
0.500	Foam	1140	67.2	3.4
0.625	Foam	930	55.0	2.8
0.750	Foam	782	46.5	2.3
0.875	Foam	675	40.1	2.0
1.000	Foam	624	37.6	1.9
0.440	Air	1172	69.3	3.5
0.500	Air	1004	59.1	3.0
0.650	Air	802	47.8	2.4
0.750	Air	696	41.0	2.1
1.000	Air	518	31.3	1.6

Table 19-H 20 Mile Route Cost - 450 MHz

Size (inch)	Dielectric Material	Cable Cost	Amp. Cost	Total Cost	Cost (per mile)
0.412	Foam	19,640	73,800	93,440	$ 4,672
0.500	Foam	25,960	61,200	87,160	$ 4,358
0.625	Foam	40,440	49,500	89,940	$ 4,497
0.750	Foam	54,380	42,300	96,680	$ 4,834
0.875	Foam	76,120	36,900	113,020	$ 5,651
1.000	Foam	100,940	34,200	135,140	$ 6,757
0.440	Air	26,280	63,000	89,280	$ 4.464
0.500	Air	30,620	54,000	84,620	$ 4,231
0.650	Air	47,200	43,200	90,400	$ 4,520
0.750	Air	66,840	36,900	103,740	$ 5,187
1.000	Air	142,440	28,800	171,240	$ 8,562

Cost Comparison for Tapped Cable Plant

We can reinforce our understanding of cable economics by examining an example of plant that includes both cable route splitting and subscriber tap losses, as would be the actual case for a rural environment system using the single-cable design technique. In our previous example we intentionally used 20 miles of plant to clearly demonstrate the cost differentials, but for this example we will limit the plant length to a more realistic ten miles.

In studies that are not included here for brevity, the author developed the average tap insertion losses incurred under three tap loading conditions for all three operating bandwidths. These conditions assumed four taps per cable mile, eight taps per mile, and twelve taps per mile. We then applied an arbitrary transmission loss per mile for typically encountered cable splitting.

Table 19-I Amplifiers Required -220 MHz

Cable Size (inch)	Dielectric Material	4 Taps per mi.	8 Taps per mi.	12 Taps per mi.
0.412	Foam	25	27	29
0.500	Foam	21	23	24
0.625	Foam	18	20	22
0.750	Foam	15	17	18
0.440	Air	23	25	27
0.500	Air	19	21	22
0.650	Air	14	16	17

Plant Costs per Mile - 220 MHz

Cable Size (inch)	Dielectric Material	4 Taps per mi.	8 Taps per mi.	12 Taps per mi.
0.412	Foam	3,232	3,412	3,592
0.500	Foam	3,188	3,368	3,458
0.625	Foam	3,642	3,822	4,002
0.750	Foam	4,069	4,249	4,339
0.440	Air	3,384	3,564	3,744
0.500	Air	3,241	3,421	3,511
0.650	Air	3,620	3,800	3,890

Table 19-J Amplifiers Required -300 MHz

Cable Size (inch)	Dielectric Material	4 Taps per mi.	8 Taps per mi.	12 Taps per mi.
0.412	Foam	30	32	34
0.500	Foam	26	29	29
0.625	Foam	23	25	27
0.750	Foam	19	21	22
0.440	Air	28	30	32
0.500	Air	24	26	27
0.650	Air	18	20	21

Plant Costs per Mile - 300 MHz

Cable Size (inch)	Dielectric Material	4 Taps per mi.	8 Taps per mi.	12 Taps per mi.
0.412	Foam	3,682	3,862	4,042
0.500	Foam	3,638	3,818	3,908
0.625	Foam	4,092	4,272	4,452
0.750	Foam	4,429	4,609	4,699
0.440	Air	3,834	4,014	4,194
0.500	Air	3,691	3,871	3,961
0.650	Air	3,980	4,160	4,250

By combining amplifier and cable costs as in our previous example, we can produce a reasonable cost evaluation, which is presented in Tables 19-I, 19-J, and 19-K. We will ignore tap or splitting costs since they would not be dramatically different for the three cases and because we are primarily trying to compare cable cost-effectiveness. A factor for annual costs per amplifier could be applied as before. Note that these costs per mile are arbitrary since they apply a $900 per amplifier cost, ignore all tap and splitting costs, and take no consideration of amplifier powering, but they do present a reasonable basis for comparison of cable sizes and types and that was our objective.

Table 19-K Amplifiers Required -450 MHz

Cable Size (inch)	Dielectric Material	4 Taps per mi.	8 Taps per mi.	12 Taps per mi.
0.412	Foam	36	38	40
0.500	Foam	32	34	35
0.625	Foam	29	31	33
0.750	Foam	25	27	29
0.440	Air	34	36	38
0.500	Air	30	32	33
0.650	Air	24	26	27

Plant Costs per Mile - 450 MHz

Cable Size (inch)	Dielectric Material	4 Taps per mi.	8 Taps per mi.	12 Taps per mi.
0.412	Foam	4,222	4,402	4,582
0.500	Foam	4,178	4,358	4,448
0.625	Foam	4,632	4,812	4,992
0.750	Foam	4,969	5,149	5,329
0.440	Air	4,374	4,554	4,734
0.500	Air	4,231	4,411	4,501
0.650	Air	4,520	4,700	4,790

We see by comparing 8 taps per mile with 0.500 inch air dielectric cable for 220, 300, and 450 MHz applications, that the cost penalty for higher transmission frequency as compared with the 220 MHz figures is approximately 14 percent for 300 MHz and approximately 29 percent for the 450 MHz application. This same comparison done for 0.500 inch foam dielectric cable also produces a cost increase of 14 percent from 220 MHz to 300 MHz and 29 percent from 220 MHz to 450 MHz.

The above tabulations may be tedious to develop and perhaps tedious to review, but they do provide a reasonable overview of cost-effectiveness under various conditions. The reader is encouraged to take a few moments to review the data because it provides some understanding and awareness of cable economics. For example, note that the cost per mile for tapped plant increases as the cable size increases.

This reflects the fact that the tap insertion loss is more significant than the cable loss. Thus, increasing the cable size to reduce the amplifier requirements and amplifier costs does not have as significant an impact as in the untapped cable example.

This discussion was not intended to endorse any particular type or size of cable, and we caution the reader against drawing conclusions prematurely. What we were trying to do was point out that particular cables may be more efficiently employed than other cables under particular circumstances. The serious student should develop his or her own examples, apply the methodology given above, and examine the results obtained for that specific application. Similar developments can be made for any type or size of cable under several tap loading conditions, and with this understanding, the reader should be well qualified for making sound cable selections.

Subscriber Service Drops

The end device to be served in all CATV systems is the subscriber-owned television set. Some interconnection, called the service drop, is required between the subscribers' premises and the transmission system itself in order to gain transmission access to the end device. The service drops must present the same transmission bandwidth as the system from which they are fed, and service drops are constructed with coaxial cable for this reason.

Some initial judgment must be made on what RF signal levels will be delivered to all subscriber television receivers. The impact on system design and costs is quite substantial if higher than necessary levels are required. This is readily apparent if we review the decision-making process.

Assume it is decided to provide a +3 dBmV input to all television receivers served. This is a generally accepted figure although there is a school of thought within the CATV industry that supports a 0 dBmV set level as sufficient. In any event, the system designer must then address the question of multiple television receivers in the subscriber's premises. If the initial signal level dedicated for service at all locations is to accommodate a second receiver, then every service location must be fed a 3.5 dB or so higher signal level to accommodate signal splitting within the location, either initially or at a later date. And some nominal allowance for inside the home cabling is also necessary.

If we arbitrarily assume a +3 dBmV minimum signal level to each receiver, and we anticipate a second set in each home, the signal level to be delivered to the outside of each home would have to be +7 dBmV or so. If, on the other hand, 0 dBmV is an acceptable television set input, then even providing for a second set we need deliver only +4 dBmV or so to the outside of the building. In either event the service drop cable loss must be provided for if we are to develop an output level specification for the subscriber tap itself.

The usual practice is to survey the service area and determine the average service drop length. It would be inefficient to simply provide signal output from all taps sufficient to accommodate the very longest drops, since the vast majority of the stations will not require this much signal. Let us assume the majority of the service drops (pole line or pedestal to exterior wall of the building) will not exceed 150 feet. The engineer equates the most cost-effective drop cable size for this length (150 feet) and adds the drop cable transmission loss to the signal level required at the outside wall of the building.

For example, if we were considering RG-59 foam dielectric service drop cable in a 300-MHz system, 150 feet of this cable would impose 6.48 dB of loss. If our earlier decision was to provide 0 dBmV to each TV receiver and sufficient signal to accommodate a second set later, then we needed +4 dBmV or so at the house. That would mean the service drop input level would have to be +11 dBmV. This would be the system layout specification for minimum output at every subscriber tap port.

If, on the other hand, we had decided to deliver +3 dBmV to every set, the signal level required at the outside wall of the building would be +7 dBmV. The same drop cable loss (6.48 dB) would now require a +13.5 dBmV output specification for each and every subscriber tap in the system. Quite obviously a higher level requirement will increase the cost of the system.

We might utilize a larger-size, lower-loss drop cable to provide higher signal levels at the subscriber's premises and minimize the tap output specification. The decision will require some fundamental understanding of the economics of service drop cables.

Service Drop Cables

Drop cables are required to be more flexible and the outer conductor is usually a braid or metallic foil or a combination of both. These cables are not designated by outside diameter but by specific JAN (Joint Army Navy) type designations such as RG-9, RG-6, RG-11, etc.

Drop cables are available in a variety of configurations including messengered or self-supporting, and with a variety of dielectric materials. Generally foam dielectric cable is used for aerial service drops, but this type of cable is somewhat more prone to mechanical damage when it is directly plowed underground. In addition, the foam dielectric may be more susceptible to moisture ingress over the long term when placed underground. Thus solid dielectric service drop cable is sometimes utilized for buried drop installations.

Cost alone is not the only consideration. Transmission loss must also be considered. In Table 19-L we present transmission losses for various types and sizes of service drop cables. In Table 19-M we show representative costs for various sizes and types of service drop cables.

As in our previous cost studies on cable, these losses and costs may not necessarily agree with current drop cable costs.

But for our instructive purposes some comparisons can be developed. One might reasonably expect the relationship of costs to size and type would remain relatively constant even if the entire scale of costs were to change. In any event it would be easy to update the cost figures periodically.

Table 19-L Service Drop Cable Losses

Cable Type	Cable Dielectric	220 MHz (100 feet)	300 MHz (100 feet)	450 MHz (100 feet)
RG-59	Foam	3.66 dB	4.32 dB	5.29 dB
RG-6	Foam	2.92 dB	3.46 dB	4.25 dB
RG-11	Foam	1.95 dB	2.31 dB	2.86 dB

Table 19-M Service Drop Cable Costs

Cable Type	Cable Dielectric	Aerial Service	Buried Service	Self-Support	Cost per 100'
RG-59	Foam		X		$ 5.30
RG-59	Foam	X			$ 5.30
RG-59	Foam	X		X	$ 6.60
RG-6	Foam		X		$ 6.50
RG-6	Foam	X			$ 6.50
RG-6	Foam	X		X	$ 7.80
RG-11	Foam		X		$ 12.70
RG-11	Foam	X			$ 12.70
RG-11	Foam	X		X	$ 15.00

Applying the Service Drop Data

Since RG-59 is the least expensive cable, we ought to examine this size as the most desirable first alternative. Our objective is to select a cost-effective cable that minimizes subscriber tap output loading and still meets end of drop signal levels.

Let us assume in every case that we must provide +4 dBmV at the end of the drop, which we will take to be the outside wall of the subscriber premises. We will do calculations for 220, 300, and 450 MHz and the reader is encouraged to extend these to 500 MHz or higher on his or her own initiative.

Assuming a 200 foot aerial drop requirement, the foam dielectric RG-59 will introduce about 7.3 dB of loss at 200 MHz, 8.6 dB of loss at 300 MHz, and 10.6 dB ofloss at 450 MHz. To provide a +4 dBmV at the end of the drop, this requires a tap output level of +11.3 dBmV for 220 MHz, +12.6 dBmV for 300 MHz, and +14.6 dBmV at 450 MHz. These levels, as design specifications for each and every system tap output port, would impose a relatively severe tap load on the system and will increase system cost.

If we examine a 200 foot service drop of RG-6 foam dielectric cable, the losses are 5.84 dB at 220 MHz, 6.92 dB at 300 MHz, and 8.5 dB at 450 MHz. To deliver the same +4 dBmV at the end of the drop, the tap output requirements now become +10 dBmV at 220 MHz, +11 dBmV at 300 MHz, and +13 at 450 MHz.

A 200 foot aerial drop would require self-supporting cable in either size. If we examine Table 19-M we see that the cost differential between RG-59 (foam dielectric self-support) and RG-6 (foam dielectric self-support) in a 200 foot length is only $ 2.40. This differential would seem to be quite acceptable as opposed to a much more severe tap load specification throughout the entire system.

If, for familiarization, we carry this a step further we could examine RG-11 cable. Now we have losses of 3.9 dB at 0 MHz, 4.6 dB at 300 MHz, and 5.7 dB at 450 MHz. Tap output levels need only be + dBmV at 220 MHz, +9 dBmV at 300 MHz, and +10 dBmV at 450 MHz to provide a +4 dBmV at the end of the drop. But the cost differential between RG-6 and RG-11 cable offers too little transmission advantage to justify this scale of cost penalty, which is $14.40 per service drop.

Accommodating Extra Long Drops

We must consider those service drop requirements that exceed the average length. In rural applications some farm residences may require substantially longer drop lengths and some basic alternatives to accommodate these are essential. Of course it is possible to simply extend the distribution plant as a radial cable leg or cable extension. This would reduce the amount of service drop losses involved by bringing the signal feed point closer to the residence itself, providing a higher signal level for tapping. In extreme cases this might even require an individual, additional amplifier, and such a selection will sometimes be unavoidable. Even in high density urban systems a remotely located or isolated single residence can impose this penalty; but since an amplifier is somewhat expensive, this should be considered the least desirable solution.

The most practical approach is to reduce the drop loss passively, which dictates the use of larger-size, lower-loss cable. For example, let us consider an aerial drop in a 220 MHz application where the drop length to the residence is 400 feet.

Suppose that even by using RG-11 foam-type cable we cannot satisfy a +4 dBmV end of drop requirement. One-half inch cable could satisfy the requirement, even though it may require placement of strand and cable lashing just as the main cable plant construction did. Now the actual drop cable (RG-6 or RG-11) would be restricted to the span from the last pole to the house itself, with the bulk of the drop being low-loss 0.500 inch cable. It is difficult to establish limits on such an arrangement since it would be dictated by the actual length of the RG-6 or RG-11 required.

Obviously the labor and materials cost of such a drop would be quite high, but in most instances this would still be more acceptable than an additional amplifier with its power consumption and long-term maintenance cost, but even this approach would have limitations.

Another possible solution would be the special selection of the tap value during system layout, to provide more than +10 dBmV signal level feed into the drop cable. This presupposes that the long drop has been identified prior to actually laying out the system, and it does introduce some additional insertion loss penalty into the system; but it may well be more acceptable than an additional amplifier simply to serve a single subscriber. We might usefully review the process of tap value selection to more fully demonstrate this technique.

For example, assume it were necessary to provide a tap to feed a service drop at a point where the signal level in the cable plant was +24 dBmV. We would normally select a tap with a 14 dB value which simply means the tap output port will deliver signals 14 dB down from the main cable input level. Since the input level was +24 dBmV, this tap would deliver the required +10 dBmV input to the service drop cable itself. Such a tap would introduce 1.0 dB of through insertion loss to the main cable, so the main cable output signal level in this case would be +23 dBmV.

We could select a lower tap value for this location. For example if we selected an 11 dB tap, the signal fed to the service drop cable would be 11 dB lower than the main cable input level of +24 dBmV. Then the service drop would be fed +13 dBmV, rather than the +10 dBmV provided with the 14 dB tap value. The 11 dB tap imposes a 1.5 dB through insertion loss to the main cable such that the main cable output level from this device would now be +22.5 dBmV, rather than the +23 dBmV using the 14 dB tap value.

Quite obviously this will require the subsequent main cable amplifier to be located somewhat closer (about 50 feet or so) and if this were done many times in a long system, might even require more amplifiers to be placed, but it does provide 3 dB higher signal level input to the service drop cable. By using this technique it is entirely possible to accommodate unusually long service drop lengths, and if there are not a great many long drops to be accommodated, the impact on system cost will be quite tolerable.

Since the actual system layout or design is produced based upon strand maps or staking sheets produced by field trips, it would be helpful if long drop situations were noted in the field trip data submitted. It is not necessary to actually measure every drop length, but all drops over 200 feet or so should be noted.

Summary

Developments along these lines permit an overview of cost-effectiveness under various conditions. The reader might consider taking a small feeder cable section of a system that he or she is familiar with and applying several types and sizes of cable to that design. If this is not possible, reviewing the data presented here again should produce some understanding and awareness of cable and drop cable economics.

Although the primary consideration in system design is technical adequacy, and this factor has priority, this in no way relieves the engineer or system designer of the obligation to produce an efficient and economical design as well. It is not particularly difficult to design a system that works, and the reader should be qualified to do so now. The mark of the professional, however, is a design that works well at a minimum cost.

In any system there are some number of service locations that are so located as to preclude reaching them in a highly cost-effective manner. The designer should not agonize over such extrordinary cases, and certainly should not cost penalize the majority of the plant to simply accommodate them. The designer must, however, be acutely aware of the impact on system costs of his or her efforts and of his or her responsibility to fully analyze all alternatives and produce, in the finished product, technically sound and economical plant.

Chapter 20

Satellite Program Acquisition

There are several satellites available as program sources for CATV operations and this availability has had a very significant effect on CATV development.

Initially, the program sources available for cable systems was strictly limited to off-air reception and the CATV system was frequently required to take extraordinary measures simply to acquire program. When available, mountain-top sites were used, with all of the associated problems of accessibility, commercial power availability, long cable runs into the service area, etc. Where natural elevation was not available, high tower structures were required and massive antenna arrays were frequently employed. Single-channel microwave systems, both private service and common carrier, relieved the situation somewhat but the variety of programs available was still distinctly limited.

Satellite technology changed all this and now provides the option of 24 or more clean, noise-free program sources delivered to almost any location in the nation at an affordable cost. Even the smallest CATV systems today include satellite receiving capability as a basic facility.

Satellite Transmission

In 1959 and the early 1960s the first communications satellites were positioned, in low, non-synchronous orbits. This was done primarily to avoid the transmission transit delays imposed by higher orbit positioning.

Figure 20-1 shows a satellite positioned 35,850 kilometers (22,275 miles) above the earth. Such a satellite is referred to as synchronous geostationary. At a 35,850-kilometer altitude, the satellite will orbit the earth in a time period equalling the earth's rotation, 24 hours. The satellite is called synchronous because its orbit is synchronized with the earth's rotation. It is called geostationary because, from earth, it appears to always be in the same location.

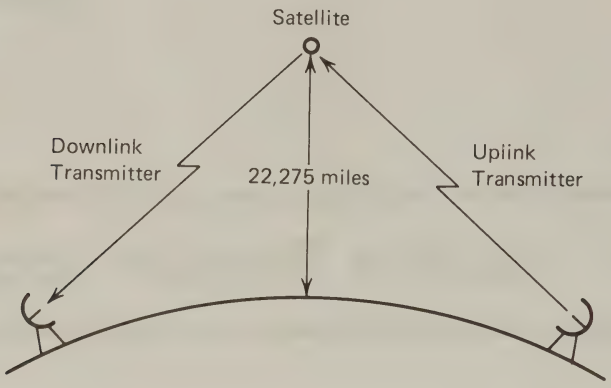


Figure 20-1 Geostationary Satellite

In non-synchronous operations, the satellite would orbit the earth at a lower altitude and thus at a higher orbital rate than 24 hours. The effect, viewed from earth, would be that of a moving satellite, and all earth antennas would have to be able to track this moving target. Of course the satellite would go over the horizon or out of sight part of the time, and the receiver would be without signal input until the original satellite came into view again, or until the receiving antenna searched for, found, and locked onto a different satellite.

In synchronous geostationary operations the earth station antennas could be fixed in place, and thus were less expensive and sophisticated. Higher-gain (larger-size) antennas could also be employed.

Consider the transmission path length in Figure 20-1. RF energy propagates in free space at the speed of light, which is 300,000,000 meters per second or 186,000 miles per second. Any signal sent from earth up to the satellite and then back down to a different receiving location on earth will take about 0.24 seconds to arrive at its destination. In television transmission this has no real significance; however, in telephone service an awkward delay in conversations is introduced. If two satellite links are involved in a long distance call it is quite a problem.

The satellite does occasionally require repositioning, accomplished with on-board jet thrusters. The amount of fuel that the satellite has on board for such repositioning is a factor in the usable life expectancy of the unit. The satellite obviously requires some launching vehicle to escape earth's gravitation, as well as substantial amounts of operating power that is derived from solar panels and batteries.

Satellites as Radio Relay Stations

For commercial satellite communications as utilized in CATV operations, 500 MHz of spectrum has been allocated in the 4 and 6 GHz frequency bands (3.7-4.2 GHz and 5.925-6.425 GHz). The 4 GHz band is utilized for down-link transmissions from the satellite to earth, and the 6 GHz band for up-link transmissions from the earth to the satellite. These frequencies are in the microwave range. By using highly directional antennas, usually parabolic dishes, the down-link energy can be directed at specific geographic areas. In effect, this provides an increase in gain since the RF energy is concentrated and focused and less widely dispersed. A contour plot commonly referred to as the "footprint" of the geographic signal strength of the satellite can be developed. The geographical location of the earth receiving station will determine the gain required in the receiving antenna and the vertical angle at which the antenna must be mounted. Quite obviously the receiver must have a clear transmission path (sight line) to the satellite or accept the attenuation of local obstructions.

The higher the transmitting power the satellite can deliver to the down-link, the less gain the earth receiving station must provide, either through low-noise pre-amplification or through higher-gain antennas, or both. The practical limitation of operating power within the satellite itself must be considered.

An example is a proposed service called Direct Broadcast Satellite (DBS). The intent was to serve home satellite stations directly. If home receiving station costs are to be economically attractive, and $300 to $400 has been stated as a target cost for this service, then much smaller receiving antennas will be required, perhaps on the order of one meter or so. This will require substantially higher RF power in the down-link transmitting equipments. Thus it is currently proposed to limit DBS satellites to three or four channels.

The satellites presently in service for CATV use can deliver 24 channels. This requires rather high-gain earth receiving station antennas, and typical sizes in use today are 4.5 meters (approximately 15 ft.) or larger.

Satellite Electronics

On board the satellite, a device called a transponder is provided for each television channel handled. A transponder is a transmitter/receiver combination that receives a signal on one frequency and re-transmits it at a different frequency. In a satellite that can deliver 24 channels, there are 24 individual transponders. Note that no demodulation/modulation process is involved. The up-link RF carrier in the 6 GHz band has been frequency modulated with the video and audio program information, and the depth of modulation is not disturbed or altered by the transponder.

Each transponder has a bandwidth of 36 MHz and a 4 MHz guard band is provided between transponder frequency assignments; thus each television channel carried requires 40 MHz. The frequency bandwidth allowed for the service was 500 MHz and only 12 television channels could be accommodated in this bandwidth.

By utilizing the isolation of cross-polarized antennas and employing both horizontal and vertical polarizations, the 12 channel frequencies may be reused, and a total channel capacity of 24 is possible. Of course the earth receiving facility must also accept signals on both polarizations if it is to provide access to all 24 channels.

It is beyond the scope of this text to go into greater detail on either antenna gains, various antenna-feed types, cross-polarized operation or other technical details of satellite receiving facility design. There are reference books available for the interested reader, and equipment suppliers can and will provide this level of engineering support.

Television Receiving-Only Stations

A CATV facility to only receive satellite TV transmissions is called a TVRO (Television Receiver Only). Obviously the antenna-feed horn must accommodate the down-link frequency band, and most generally a dual polarized feed is provided so that all 24 transponder frequencies may be accessed.

Just as with cable amplifiers in our earlier discussions, our concern is with C/N ratio, and that relates to input RF level and receiver noise figure. Intermodulation distortion is not a consideration in single-channel receivers, of course, but is a factor in low-noise amplifiers (LNAs) and converters that are broadband devices processing several carriers.

Since the signals from the satellite are frequency modulated for noise improvement we must demodulate and modulate to AM (vestigial sideband) for application to the cable distribution plant. The individual satellite receiver is the demodulator, and produces an audio and video output. This audio/video is applied to a conventional RF (VHF) modulator to produce a VHF carrier. There are basically two types of TVRO facilities in use today.

4 GHz TVRO

One type makes no conversion of the received microwave signals before feeding each individual FM receiver. Due to the low received RF levels at the antenna a LNA (low noise amplifier) is used to protect the C/N ratio of the received microwave signals and to offset the antenna feed line losses, as well as the RF power divider losses incurred in feeding several receivers. In this case all the satellite receivers must have a microwave frequency (4 GHz band) front end. A LNA is required for each polarization feed horn output.

Figure 20-2 shows a 4 GHz type of TVRO with four receivers connected to each polarization through two antenna feed lines. Note the requirement for an RF (VHF) modulator in addition to a satellite receiver for each television channel derived.

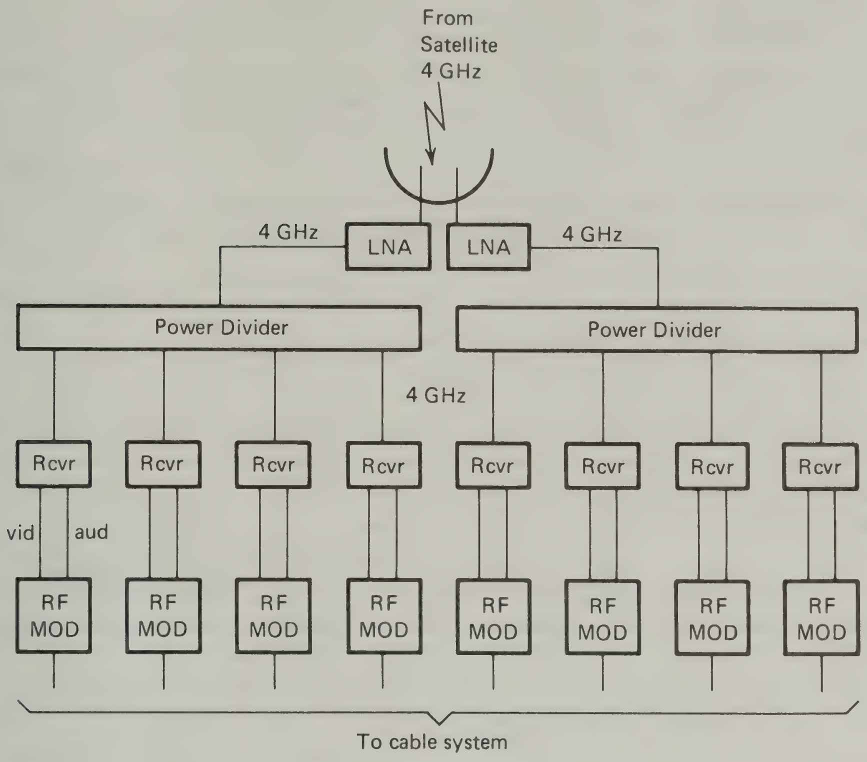

From
Satellite
4 GHz
4 GHz
LNA
LNA
4 GHz
Power Divider
Power Divider
4 GHz
Rcvr
vid
aud
RF
MOD
To cable system

Figure 20-2 4 GHz TVRO

Converter TVRO

The second type of TVRO facility uses a combination low noise amplifier and converter at the feed horn of the antenna. In this case the LNA/converter converts the entire spectrum from 4 GHz down to the 900 to 1,500 MHz range right on the back of each feed horn. The antenna feed line is now no longer passing microwave frequencies and a less expensive coaxial cable can be employed. The major advantage of this technique is that none of the individual receivers need be designed for microwave frequency (4 GHz) input, thus all receivers are somewhat less sophisticated and less expensive.

Figure 20-3 shows a TVRO of this type with four receivers connected to each polarization through two antenna feed lines. Note the requirement, as before, for an RF (VHF) modulator as well as a satellite receiver for each channel derived.

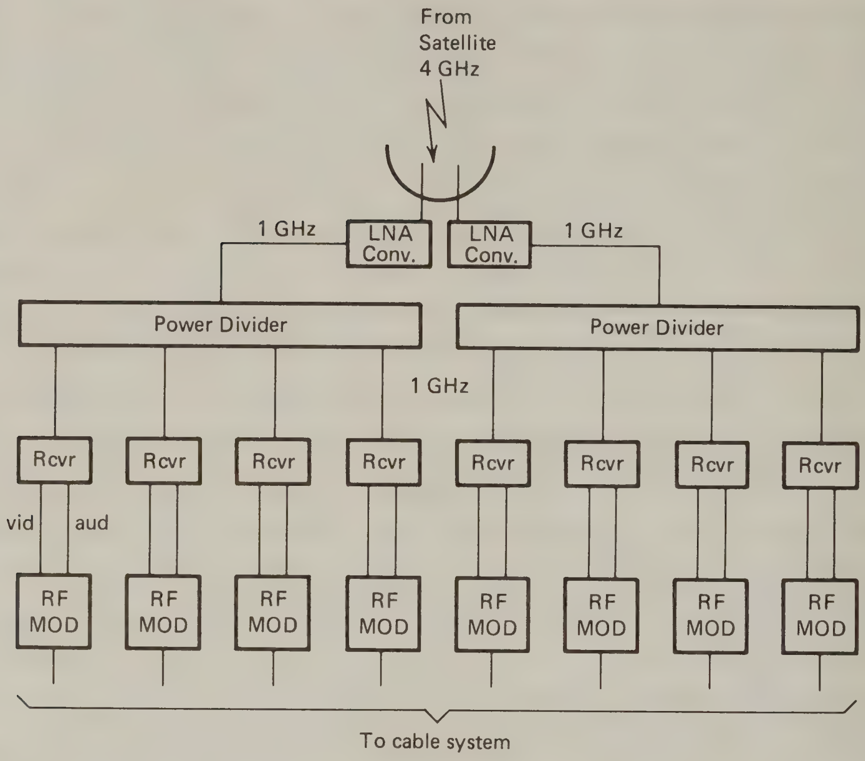

From
Satellite
4 GHz
1 GHz
LNA Conv.
LNA Conv.
1 GHz
Power Divider
Power Divider
1 GHz
Rcvr
vid
aud
RF MOD
To cable system

Figure 20-3 Converter TVRO

General Discussion

In general, a TVRO facility is somewhat like a head end or microwave transportation facility in that everything is processing single channel signals until after the RF (VHF) combining has taken place, which is after the signals have been demodulated and then modulated again, with the exception of the microwave frequency LNA or LNA-converter.

There are some characteristics that CATV people may be unfamiliar with, however. At microwave frequencies (4 GHz) the received signals may be subject to fading during heavy rainfall periods; thus some fade margin is usually provided during facility design. This generally involves using a larger-size, larger-gain antenna. During heavy snowfall or icing conditions, snow or ice can accumulate in the dish itself, distorting the antenna pattern and sometimes dramatically reducing antenna gain. This condition is particularly prevalent where the antenna is almost horizontal in orientation.

There may be local, terrestrial (point-to-point) microwave links in service nearby, which can be interfering if the TVRO antenna captures some of that RF energy. There are companies that will perform an interference study using a computer to provide an estimate of such potential interference. At the present time no federal license is required for receive-only stations and no personnel licenses are necessary to service such equipment.

A wide variety of features such as tunable, fixed tuned, remote tunable, etc., are available in satellite; however, the basic principles remain the same.

Program Scrambling

It is possible for the cable system operator to scramble the television signal in any of several ways before applying that signal to the cable distribution system itself. Scrambling is one technique for excluding some cable subscribers from some of the programs either part or all of the time. This is usually done to create an additional level of subscriber service at additional service charge. If scrambling is done at the option of the CATV operator, an encoding device of some sort must be inserted, probably between the TVRO receiver and the RF (VHF) modulator.

The program supplier may elect to scramble his video before he transmits it up to the satellite in order to protect his own revenues from unauthorized or nonpaying users. In this case, to recover normal video at the TVRO station, a de-scrambler would be required between the TVRO receiver and the RF (VHF) modulator. Of course the scrambled video received from the satellite could also be passed directly to the RF (VHF) modulator without de-scrambling.

In any event, whichever encoding (scrambling) technique is employed and wherever it is applied in the system, it will require some decoding (de-scrambling) device at every subscriber station authorized or entitled to view the scrambled program.

Summary

Maintenance of TVRO facilities is largely a matter of periodic inspection and signal level and quality monitoring and should present no serious difficulties to CATV technicians. The presence of video at each receiver output does suggest that TVRO facilities be equipped with video monitor capability to facilitate picture quality monitoring, and as in any RF modulator equipment, some care is required in setting the depth of modulation for the AM (vestigial sideband) RF output carriers.

Chapter 21

Head End Signal Processing

The head end is the point of origin for signal distribution throughout a CATV operation. It may not be the only point of origin because some signals may be generated or inserted at subsidiary distribution points or hubs. And sub-system distribution facilities such as microwave or super-trunking may be involved before local distribution cable plant is encountered. But the major distribution point is usually identified as the head end.

In an earlier chapter we discussed satellite program acquisition in some depth. The only program sources we have yet to cover are locally originated program sources and off-the-air received signals. We will confine ourselves to the head end equipments alone including multiplexing (combining) techniques, ancillary equipments, and the special features of head ends.

Strip Amplifiers

One earlier techniques for handling off-air reception of broadcast TV signals are shown in Figure 21-1. It consisted of a series of identical broadband amplifiers, each with a bandpass capability covering the standard VHF band of 54 to 216 MHz. These were called "strip amplifiers." To avoid intermodulation problems they were operated as single-channel devices by using single-channel bandpass filters in front of and often behind each amplifier.

The shortcomings of this approach were that it provided only limited rejection to non-desired signals which might pass through both filter and amplifier, and could produce interfering beat products and intermodulation distortion. It also provided only marginal individual control of sound and picture carriers, AGC was limited, and channel conversion to a different frequency was not possible within the unit itself.

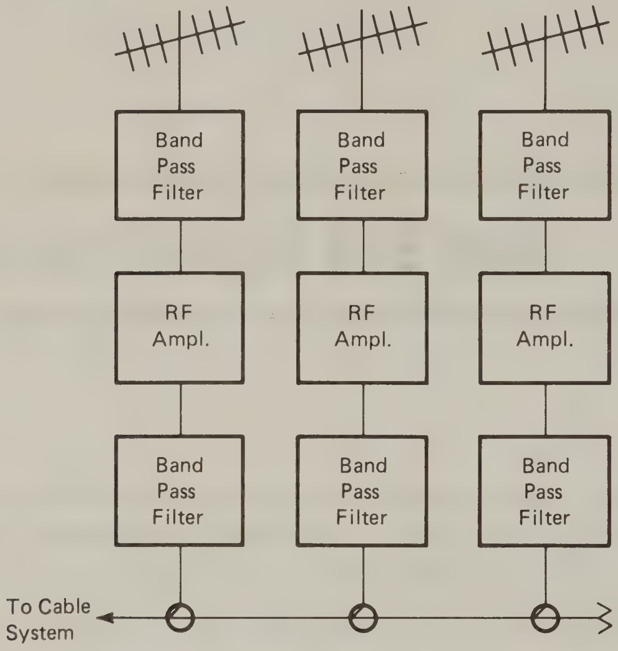


Figure 21-1 Strip Amplifiers

Demodulator/Modulator Technique

The industry then turned to a demodulator/modulator method that connected the units back-to-back on a video/audio basis as shown in Figure 21-2. Appropriate bandpass filters on the demodulator input plus its inherent selectivity made this a satisfactory method to produce clean, distortion-free video; the complexities of re-modulation were a bit sophisticated, however. Channel frequency changes were easy but the quality of output signals (RF/VHF) was a function of setting modulation depth both for audio and video, a technique which some CATV technicians were not familiar with. It also introduced the question of RF carrier frequency stability, since the signal carrier applied to the cable system now originated within this unit itself.

Heterodyne Processor

The industry moved on to a heterodyne signal processor of the type shown in Figure 21-3. This is the most common technique in use today for off-air signal processing and consists of a down converter that beats (heterodynes) the input RF carrier against a local oscillator generated carrier.

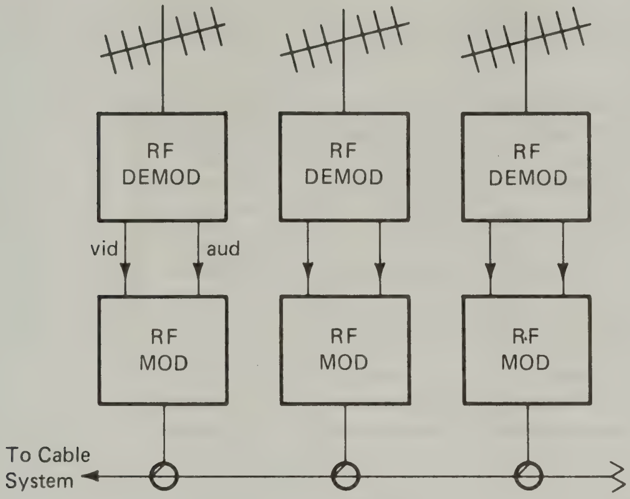


Figure 21-2 Demodulator/Modulator

This produces a standard intermediate frequency (IF) carrier, which is then applied to a rather sophisticated IF amplifier with excellent selectivity and AGC. Since all signal processors utilize identical IF amplifiers, a sophisticated design is affordable. The output of the IF amplifier is applied to an up converter which again employs a local oscillator, and thus the RF carrier output can be selected to be any convenient or desired cable TV frequency (VHF).

Since all IF amplifiers are processing the same frequency carrier, program can be switched between units on an IF basis. For example, a single modulator with an IF carrier output can provide emergency program override or substitution for system-wide emergency announcements on all system channels simultaneously. We have positive control of both sound and video carrier levels, and since no demodulation has taken place, the relationship between picture and aural carriers remains as originally established by the broadcasting station. The equipment is quite flexible. When a UHF off-air channel is involved we need only change the input down converter unit to produce the same IF frequency.

Many additional features such as stand-by carrier generation were developed, whereby the cable plant was fed a carrier even if the off-air signal was interrupted. This allowed use of the output RF carriers as pilot signals for system amplifier AGC or ASC purposes. We were completely free to make on-channel or off-channel conversions with only minor restrictions. Thus an off-air Channel 3 could be processed to present a Channel 3 input to the cable plant or to present a Channel 6 or 11 or whatever channel we might wish.

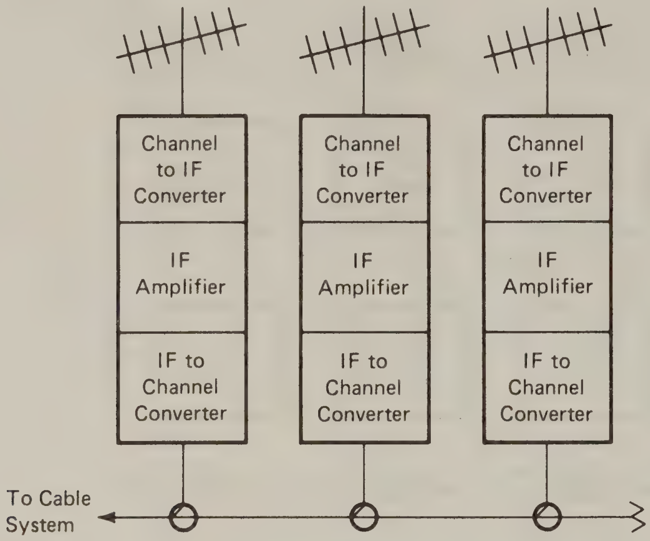

Channel to IF Converter
IF Amplifier
IF to Channel Converter
Channel to IF Converter
IF Amplifier
IF to Channel Converter
Channel to IF Converter
IF Amplifier
IF to Channel Converter
To Cable System

Figure 21-3 Heterodyne Processor

An important but sometimes overlooked capability of the heterodyne processor is its provision for sub-channel-to-IF conversion. Television signals delivered to the head end at sub-band frequencies (5 to 30 MHz), either from sub-band super-trunk facilities or from the return (upstream) transmission of the distribution plant, can simply be heterodyned to an appropriate frequency for addition to the downstream VHF signals. The heterodyne processor has become the industry standard for RF-to-RF signal handling.

Preamplifiers

When an off-air signal at the receiving antenna is of such a low level that the antenna down lead losses will produce an unsatisfactory C/N ratio at the input to the head end equipment, a preamplifier is often employed. Note that this condition can apply equally to demodulator or heterodyne signal-processing equipment. The condition is the same as we discussed in the earlier chapter on noise.

In Figure 21-4 we show a heterodyne processor receiving an off-air signal through 300 feet of coaxial cable between the unit and the tower-mounted receiving antenna. Let us assume the down lead cable introduces 5 dB of loss.

A typical heterodyne processor noise figure (NF) might be 6 or 7 dB. We will use 7 dB for our discussion. Our first case assumes that no preamplifier is installed and the RF signal received off the off-air antenna is at a -15 dBmV level.

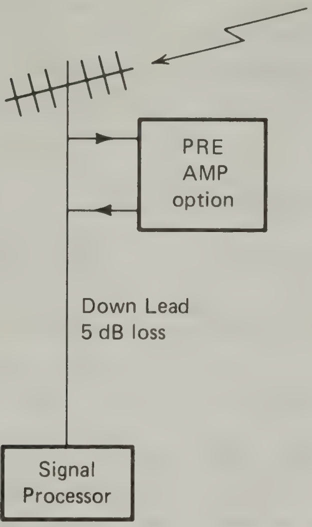


Figure 21-4 Preamplifier

With 5 dB of down lead cable loss, the input to the processor would be -20 dBmV. The formula for C/N ratio is

$$C/N = Sig_{in} + 59 - NF$$

where C/N = C/N ratio of the heterodyne processor
Sig_{in} = processor input signal level (dBmV)
59 = thermal noise in a 4 MHz bandwidth
NF = processor Noise Figure (dB)

The processor C/N ratio in our example calculates to be

$$C/N = (-20) + 59 - 7$$

$$C/N = 32 \text{ dB}$$

If we anticipate any noise contribution from the subsequent cable distribution plant at all, and of course we must, typically this might be a C/N ratio of 42 dB or so and the end-of-system C/N ratio would be a combination of the two ratios. Table 4-4 shows that a 32 dB C/N ratio and a 42 dB C/N ratio combined will produce a 31.6 dB C/N ratio at the end of the system. This would be totally unacceptable. Now let us try a preamplifier at the antenna output on the tower structure.

If we had a preamplifier with a 5 dB NF and 20 dB of gain, the only other factor we need for analysis is the off-air signal level out of the antenna itself. By assuming three different received RF levels we can easily see the value and application of a preamplifier. We will use -15, -5, and +10 dBmV in this discussion. The preamplifier C/N ratio would be

$$C/N = Sig_{in} + 59 - NF$$

Input -15 dBmV	Input -5 dBmV	Input +10 dBmV
$C/N = (-15) + 59 - 5$	$C/N = (-5) + 59 - 5$	$C/N = 10 + 59 - 5$
$= 39$ dB	$= 49$ dB	$= 64$ dB

With 20 dB of preamplifier gain and an input signal level of -15 dBmV, the preamp output level would be +5 dBmV. The down lead cable loss was given to be 5 dB, so the input to the heterodyne processor itself would be 0 dBmV. This is the same unit we used in the earlier example, so the C/N ratio of the processor would be calculated as before using this new input.

$$C/N = 0 + 59 - 7$$

$$= 52 \text{ dB}$$

Combining a 52 dB C/N ratio for the processor with a 39 dB ratio for the preamp the resultant head end C/N ratio is 38.8 dB which, when combined with the cable plant C/N ratio of 42 dB, gives a total C/N ratio of about 37 dB. Not satisfactory perhaps, but substantially better than the 32 dB of the earlier example that provided no preamplifier at all.

Let us do the entire development over using the higher antenna output of -5 dBmV. With no preamp the processor input would be -10 dBmV, reflecting the 5 dB down lead cable loss. The processor C/N ratio would be calculated as:

$$C/N = (-10) + 59 - 7$$

$$= 42 \text{ dB}$$

Combined with a 42 dB C/N ratio for the cable plant, the system C/N ratio would be 39 dB or very nearly so. This is not acceptable. But if we use the preamplifier with the -5 dBmV antenna signal, the preamp C/N would be 49 dB as we calculated earlier. Given 20 dB of amplifier gain the preamp output would be +15 dBmV, and after the 5 dB of down lead cable loss, the processor input level would be +10 dBmV. Under this condition the processor C/N ratio can be calculated to be 62 dB.

The reader is encouraged to perform this calculation to reinforce understanding of the process. Combining a preamp C/N of 49 dB, a processor C/N of 62 dB, and a cable plant C/N of 42 dB, the total C/N ratio would be an acceptable 41.4 dB.

In the last case, with an antenna output signal level of +10 dBmV, using no preamplifier would produce a processor C/N ratio of 57 dB and this, combined with the cable plant C/N of 42 dB, would produce a system C/N ratio of 41.1 dB. The reader is encouraged to pursue the calculations using the preamplifier, and to determine the end-of-system C/N ratio under these conditions.

The purpose of this exercise was to understand the use and value of a preamplifier and especially its effect on end-of-system performance.

A preamplifier is an active item of equipment mounted at the top of a tower. Quite obviously where it is not required, it should not be used; but it cannot be avoided in cases of very low off-air signal levels and it can make a significant improvement in end-of-system performance. In some cases the off-air signal level is simply too low to be usable and little can be done to salvage the situation except possibly stack several antennas to develop a higher off-air signal level. Such antenna stacking is beyond the scope of this text.

Sometimes the evaluation of using a preamplifier will be based upon a computer readout of signal reception predictions for a proposed site. In other instances, if subscriber service complaints are monitored and reviewed, it may become apparent that a particular channel is reported to be noisy under particular atmospheric conditions. An analysis similar to those given in our examples may point out some possible improvements in existing, operating systems for such cases at a nominal cost, by installing a preamplifier.

Pilot Tone Carriers

In the early days of CATV development the control carriers used in providing AGC and ASC self-regulation in system amplifiers were usually provided by separate carrier generators that were installed at the system head end for that express purpose. This added one or two carriers to the number of signals carried on the system, of course. As we kept increasing the channel loading of the system from 12 to 20 to 35 channels and up, it was recognized that by utilizing in-service video-modulated carriers for regulatory purposes we could reduce the number of signals passed through each amplifier, thus reducing the intermodulation distortion somewhat. Today most cable amplifiers regulate on system TV carriers that are actually carrying video program.

Head End Signal Combining

Various units are available from manufacturers for combining all head end individual RF carriers so as to present them all to a single head end output cable. The combining function should provide good isolation between individual units and some significant transmission loss is inevitably incurred.

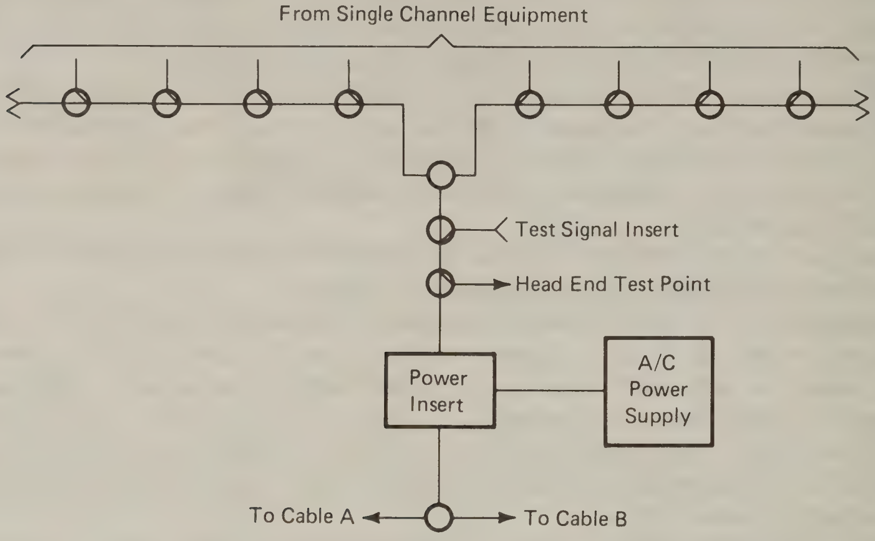


Figure 21-5 Signal Combining

Figure 21-5 shows one commonly employed combining technique using directional couplers and splitters. Note that the couplers are installed backwards, that is, reversed from their normal signal-splitting application, in order to improve the isolation between the individual signal processing units. Figure 21-5 also shows a head end test point which is usually provided for signal level monitoring and testing. We included an extra directional coupler in the figure for inserting special temporary test signals, such as a sweep generator for periodic system realignment, etc.

A good operating practice for any system is to prominently post the normal signal level readings at the head end test point, along with a log sheet for subsequent measurements made at that same point. This helps analyze trouble conditions that may subsequently develop.

Miscellaneous Head End Functions

There are many special functions and services that may add to the head end sophistication but it is beyond the scope of this text to discuss them all. Two of the more common requirements are powering some of the cable plant and providing access for any return transmission signals.

The head end is often a convenient location to install an AC power supply particularly if the output is split to serve two individual distribution cables. In this instance the head end equipments should be isolated for 60 Hz AC power and the splitter employed must include power-passing capability.

We have included a power supply in Figure 21-5 for illustrative purposes. When a system is designed for two-way (bi-directional) capability, and almost all new systems are today, some provision is necessary at the head end for extracting the upstream (return) transmission information. In Figure 21-6 we have inserted a two-way filter in each of the two individual distribution cables for this purpose.

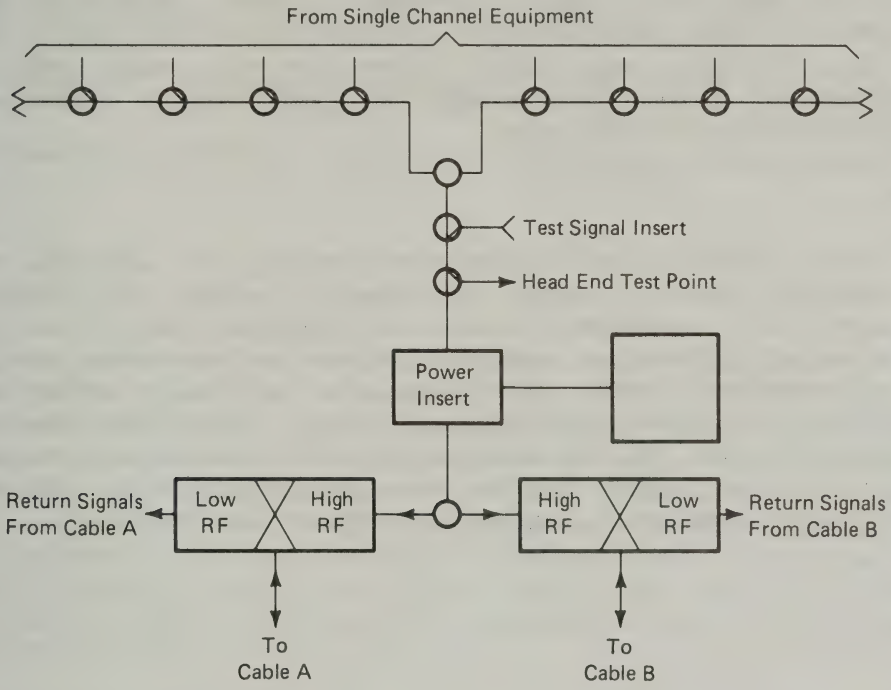

From Single Channel Equipment
Test Signal Insert
Head End Test Point
Power Insert
Return Signals From Cable A
Low RF
High RF
High RF
Low RF
Return Signals From Cable B
To Cable A
To Cable B

Figure 21-6 Signal Combining and Two-Way Operation

It would be technically acceptable to use a single two-way filter for this purpose and locate it on the single-cable (head end) side of the splitter. By using two separate filters in the manner shown in Figure 21-6, however, it isolates both cables from the point of view of return transmission. Thus more spectrum is available in each individual cable since all return transmissions do not share a single return path. It may also be possible to repeat return transmission carrier frequencies in the second cable since both cables are isolated. This could reduce the number of return transmission frequencies required and thus reduce the cost of return transmission station equipments.

Another good reason for isolating sections of the return transmission system has to do with transmission noise reduction as we discussed in Chapter 17 when we examined two-way systems.

Although we have not shown a Local Area Network (LAN) head end configuration it might have a greater variety of head end modules and return units because there might be more signals involved. But the techniques of spectrum isolation and signal combining in a LAN head end would not be dramatically different than those we have discussed here. This is also true of CATV systems that might include station addressability capability or return transmissions from either subscribers or from status monitoring units at system amplifier locations.

Summary

The advent of new services such as alarm reporting, video scrambling, even computer-controlled subscriber connect and disconnect functions will undoubtedly introduce new levels of sophistication in head end installations. Many of these new services are as yet embryonic and transmission interfaces and modulation techniques are not yet standardized. However, all of these, either as digital or analog signals, simply represent new information to be presented to or recovered from the coaxial cable transmission system. The basic understanding of RF transmission over coaxial cables and some knowledge of the head end functions and its relationship to the cable plant should provide a sound basis for adapting any new services as they emerge.

Chapter 22

Signal Transportation in CATV Systems

It is sometimes necessary or desirable to transport a multiplicity of television signals from one central point to several other points much as we did using supertrunk. There are a number of transmission technologies that may be used and we will discuss some of them here. The difference between signal distribution and signal transportation, as we use the terms here, is that distribution is the transmission through coaxial cable plant throughout a service area with the express purpose of directly serving end users or subscribers within that area. Transportation is the delivery of a signal or signals to one or more discrete points where those signals may be applied to a distribution system, and a transportation system does not generally serve any subscribers at all en route.

Microwave Transmission

Microwave transmission systems are employed in CATV operations to transport television signals or other information from one point to another. This is radio transmission through space and no coaxial cable between the two points is required.

The FCC has allocated the frequency band 12.7 to 13.2 Gigahertz (GHz) for CATV service. One Gigahertz is one billion Hertz, or one billion cycles per second. As a point of reference, standard broadcast TV Channel 13 is at 211 MHz. The microwave band is 12,000 MHz or 12 KMHz (12 GHz). At these high frequencies the transmission losses of coaxial cable cannot be tolerated, thus waveguide is utilized for antenna feed connections and high-gain, parabolic reflector antennas are utilized.

When we incorporate sub-system transportation facilities such as microwave into CATV operations we are entirely free, if it is particularly advantageous to do so, to utilize other signal modulation techniques than those that might be employed in the cable distribution system. Frequency modulation (FM) for example, may provide some significant noise improvement.

Then in sub-systems such as microwave links, super-trunk cable plant, lightwave transmission links, or even in satellite program delivery we can utilize FM techniques. We still have to consider the interface with the CATV subscriber's television receiver, the end device the system serves. These receivers are only capable of accepting AM (vestigial sideband) RF signals. Thus subsystems employing other modulation techniques require some demodulation/remodulation process in order to present AM (vestigial sideband) RF carriers to the distribution cable plant itself.

Microwave Path Engineering

The transmission engineering required for a CATV microwave link is entirely conventional. It involves path clearances (line-of-sight), transmitted power level, antenna gains, transmission line losses (antenna feed waveguides), and the free space loss (path length) between antennas. Such factors as rainfall attenuation (fading), reflective terrain features, and earth curvature complicate the process, but all of these must be equally considered in microwave path engineering for services other than CATV.

It is beyond the scope of this text to pursue path calculations and analysis in any greater depth. The CATV technician will rarely be called upon to do such work and there are many standard reference books available on the subject, and microwave equipment manufacturers frequently offer such services. But it is necessary to have some understanding and familiarity with the technique and equipments since it may be part of the overall CATV system. We will discuss microwave transmission from that point of view.

General Discussion

In CATV operations it is frequently necessary or desirable that a single microwave transmitting facility serve several different receiving locations. It is not always required that a CATV microwave system have two-way transmission capability. This restriction on bi-directional capability is primarily dictated by the requirements or nature of the CATV service and not by the inherent limitations of microwave transmission technology.

In these two respects CATV microwave systems do vary somewhat from other microwave applications. For example, microwave systems for telephone trunking applications invariably require bi-directional capability and very rarely distribute the transported information to two or more separate receiving locations.

To accommodate multi-path transmission from a single microwave transmitting facility, power splitters, waveguide couplers, and circulators are used in much the same fashion that splitters and directional couplers are employed at lower RF frequencies in coaxial cable systems.

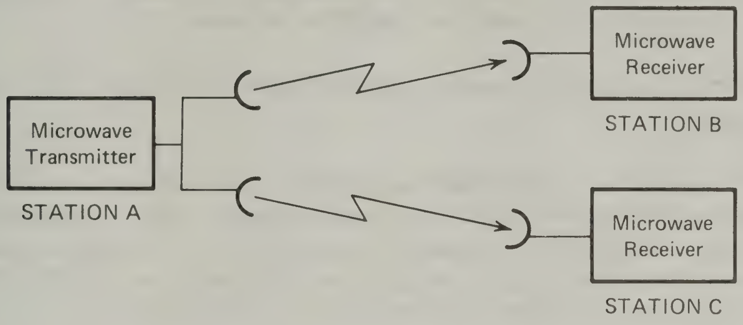


Figure 22-1 Single Channel Microwave

Figure 22-1 shows a single microwave transmitter located at station A. Using a waveguide power splitter, the RF energy from the transmitter output (at microwave frequency) is divided equally; then separate individual waveguides are used to direct RF energy to two separate parabolic antennas. Each antenna is oriented toward a different receiving location, identified in Figure 22-1 as stations B and C. In the example shown, the reduction in transmitter RF output due to division of available RF energy would be a factor in the transmission calculations of each transmission path. If necessary the reduction in RF energy in either path might be offset by utilizing larger size, higher-gain antennas or a higher RF output transmitter or both.

In CATV operations, as many as four, five, or even more individual microwave paths might be fed from a single transmitting facility. This amount of power splitting often requires both large size antennas and higher RF transmitter output. Each individual microwave path must be calculated and analyzed individually.

Microwave Applications in CATV Systems

Microwave transmission is incorporated into CATV operations as an alternative to RF transmission over coaxial cable, which is the conventional CATV technology. There may be many reasons why microwave would be considered or implemented:

1. It may be more cost-effective in eliminating the need for multiple sophisticated, off-air or satellite receiving installations at several locations.

2. It may be necessary to overcome some unusual geographical construction problems such as rivers, bridges, superhighways or exceptionally inaccessible terrain.

3. It may be provided as a mobile or temporary signal acquisition facility such as in a van used for local public events or sports contests.

4. It may be employed to avoid the transmission degradation introduced by an alternative long coaxial cable route with many amplifiers in cascade.

5. It might be considered more reliable than a long cable route with many amplifiers in cascade.

6. It may improve the commercial management of a widespread CATV operation by consolidating several smaller cable distribution systems into a single origination point. In such cases, encoding or decoding (scrambling) of television signals may be more cost-effective. And the functions of program origination or insertion of commercial advertising could be more efficiently accomplished at a single point.

7. It may be advantageous to initiate service into widely separated sections of the service area quickly. Microwave transmission can be effectively used to accomplish this purpose.

Today there are two distinctly different techniques used in CATV microwave, with advantages and disadvantages unique to both. Both are analog in nature. Digital microwave equipment, although quite commonly employed for digital telephone and data transmission systems, is not as yet widely available for television transmission.

Single-Channel Microwave Technique

We will refer to the first technique as single channel. An RF transmitter, frequency modulated, is required for each individual television signal transported. This transmitter can and usually does accommodate both program video and audio and can often also handle some limited number of additional audio channels.

At each receiving location, a separate microwave receiver is also required for each television channel. The input to each transmitter and the output of each receiver, is the video and audio information for a single television signal. This presents no problems at the transmitting terminal if the television signal is already available as video and audio. This would be the case, for example, if the original source were a video studio camera or a video tape machine. This would also be true of satellite-derived signals where the output of the satellite receiver is video and audio information.

In the case of an off-air signal we have no option but to demodulate the off-air signal, since the single-channel microwave transmitter requires a video/audio input. And in every instance, since we produce a video/audio output from the microwave link, we must provide an RF (VHF) modulator at the microwave receiving location if we intend to apply the television signal to a cable distribution system.

Thus the single-channel microwave system does introduce several demodulation/remodulation processes. It requires some sophistication on the part of servicing personnel and test equipments to preserve the video quality of the signals during these processes.

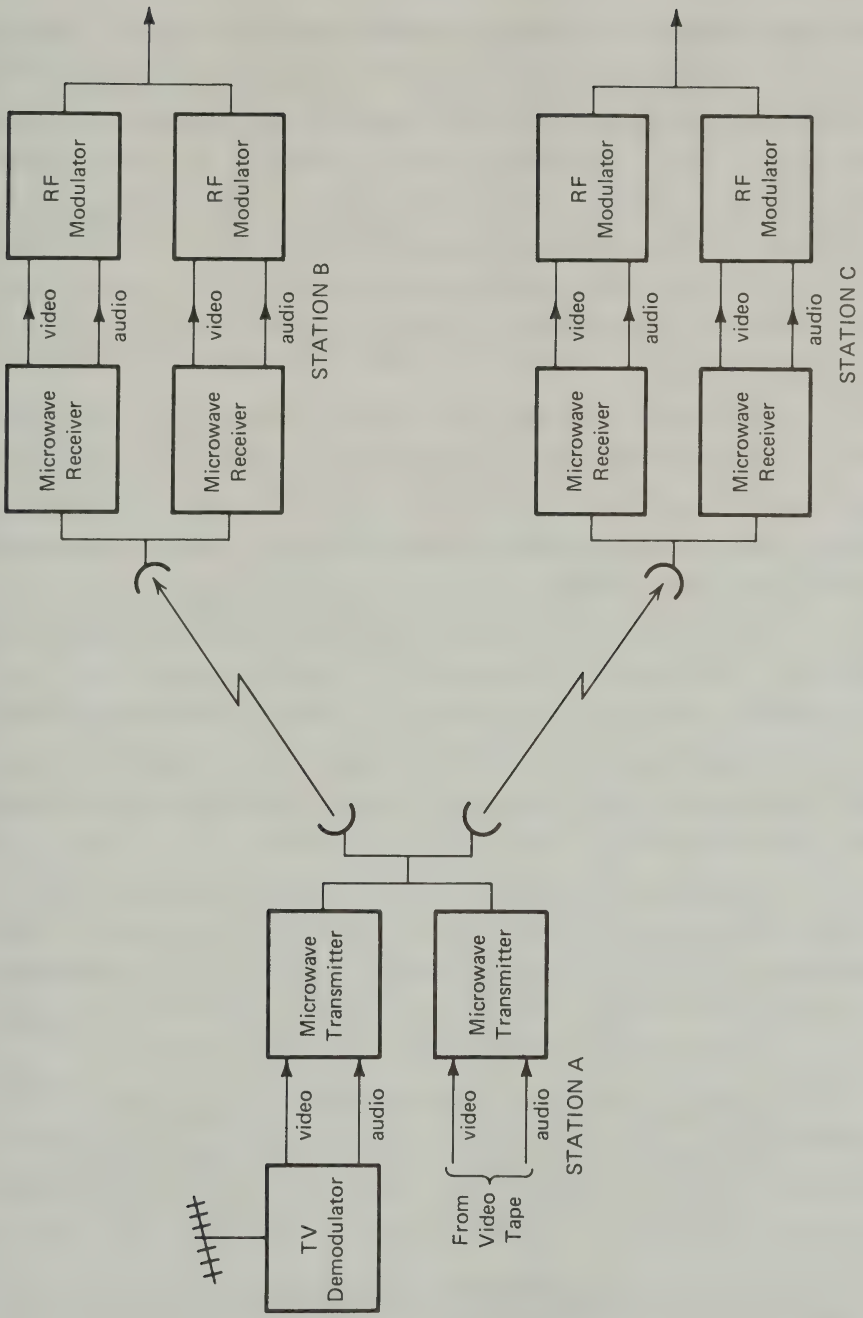

TV Demodulator
video
audio
Microwave Transmitter
From Video Tape
video
audio
Microwave Transmitter
STATION A
Microwave Receiver
video
audio
RF Modulator
Microwave Receiver
video
audio
RF Modulator
STATION B
Microwave Receiver
video
audio
RF Modulator
Microwave Receiver
video
audio
RF Modulator
STATION C

Figure 22-2 Two Channel Application

The single-channel equipment is processing a single television signal only. Although setting the depth or level of modulation is somewhat critical, the single-channel technique does not contribute any significant intermodulation distortion to the intelligence transported though other forms of distortion are a factor, such as group delay, etc. Through the use of heterodyne repeater equipments that eliminate demodulation and remodulation at each intermediate microwave repeater point, it is possible to extend single-channel microwave systems through many repeater stations. Thus systems a hundred miles or more in length are quite practical.

In Figure 22-2 we show a two-channel system feeding two receiving sites. Channel 1 is derived from an off-air television signal, and note the requirement for a demodulator in this case. Channel 2 is produced from a video tape player. Note that no RF demodulator was necessary.

But at both receiving locations, both channels required RF (VHF) modulators to produce RF carriers suitable for direct application to the CATV coaxial cable plant. This is also required because the microwave link was frequency modulated and the television receivers that will receive the cable signals require an amplitude modulated signal input. Thus it is not possible to simply frequency convert or heterodyne process the received RF microwave signals.

It is quite practical, using waveguide circulators and diplexers, to connect several transmitters and/or several receivers to the same microwave antenna. Thus multichannel or bi-directional transmission or combinations of both are possible. In Figure 22-3 we show two channels transmitting from station A to station B, and one channel transmitting from station B to A. All of these signals utilize the same antenna feed waveguides and the same parabolic antennas. Of course all RF (microwave frequency) carriers must be in the frequency band that the antenna, antenna feed horn, and the waveguide are designed to accommodate.

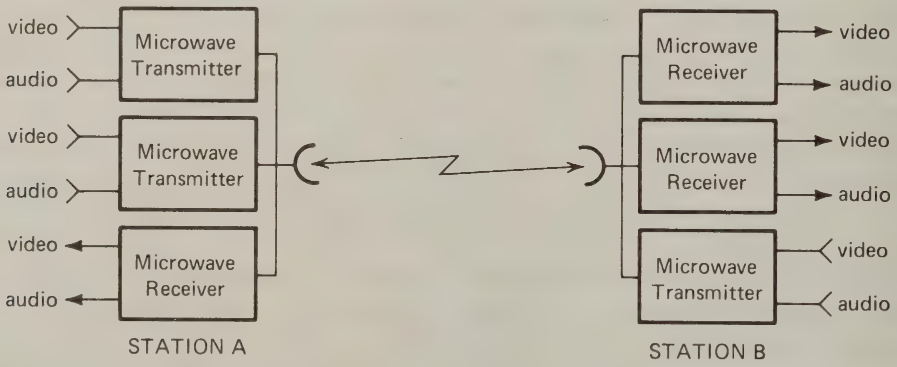


Figure 22-3 Two-Way Application

In operating CATV systems single-channel equipments of this type are frequently used as follows:

1. As video/audio feed to the main head end from mobile television vans covering temporary events.

2. As permanent video/audio feed from a convenient, centrally located television studio, to a less convenient main head end or distribution center.

3. To bring in video/audio from some distant location where a desired off-air channel might be available. This might require a single-hop or multiple-hop microwave system.

4. To provide a permanent video/audio feed from several program origination points such as schools, sports arenas, etc., to the main head end.

5. To provide a single- or two-channel video/audio feed back to the main head end from a hub or local distribution center which is simultaneously being fed many television signals over a multichannel microwave link. Single-channel equipment can be diplexed onto the multichannel equipment antennas.

Multichannel Microwave Technique

The multichannel microwave technique is quite different. There is no true modulation or demodulation process involved at all. Called AML (amplitude modulated link), the equipment accepts at the transmitter input, RF carriers at standard cable television frequencies which are already modulated with video and audio information. The term AML is a registered trademark for equipment manufactured by Hughes Microwave Communications Products. Each AML channel transmitter is actually a heterodyne up-converter that produces a microwave frequency carrier from the VHF frequency input carrier. It does not disturb or reestablish either the depth of modulation or the relationship between color or audio sub-carriers that are normally present in a VHF television signal.

Note that the terms "VHF television signal" and "standard cable television frequencies" do not necessarily denote the standard broadcast VHF frequencies such as Channels 2, 5, 9, etc. There are VHF carrier frequencies unique to the cable system in addition to the standard broadcast frequencies. For example, mid-band or super-band VHF carriers that might fall within 120 to 170 MHz or 216 to 300 MHz, or even higher.

The AML (multichannel microwave) equipment involves only a frequency conversion process and the bandwidth occupied by any TV channel in the higher microwave frequency spectrum (12 GHz) is precisely the same as the bandwidth that same channel occupied or required at the lower VHF frequency range.

Low-Power Multichannel Equipment

To avoid intermodulation distortion problems, each channel in an AML system is heterodyned up in frequency by its own individual converter unit. To provide sufficient RF energy for satisfactory microwave transmission, an RF power amplifier is then provided. This is a broadband device, and the output of several individual channel converters, at microwave frequency, are combined before they are all passed through the AML power amplifier. Since many carriers are passed through this wideband power amplifier, a reflex klystron in AML equipment, intermodulation distortion within this amplifier becomes a consideration and, in effect, limits the practical RF gain that may be used.

Quite often in CATV operations the AML transmitting facility is required to serve four, five, or six different receiving locations. Distributing the available transmitter RF output across many transmission paths can produce marginal transmission performance or inadequate fade margins on some or all of the individual links. Although the line-of-sight transmission path lengths may not be excessive, this division of available RF energy sometimes requires higher offsetting RF transmitter output levels. And at the frequencies involved, 12 GHz, rainfall fading is not insignificant either.

For the above reasons and to limit intermodulation distortion, the low-power version of AML transmitters combines only up to eight converter outputs, and passes only eight carriers through the RF broadband amplifier. When more than eight signals must be transported, a second RF amplifier is provided. The AML equipments available today can be expanded out to 54 channel capacity and more in this manner, all using a single, common waveguide and antenna installation.

High-Power Multichannel Equipment

A second version of the equipment that functions essentially in the same way but provides an RF amplifier (reflex klystron) for each individual channel converter, permits much higher RF output levels, since intermodulation distortion is distinctly limited. This equipment is more expensive but is sometimes the only solution for the following conditions:

1. Path lengths are very long.
2. There are many paths to be fed.
3. Propagation (rainfall fading) is particularly severe.
4. Unusual path conditions such as highly reflective terrain features exist.

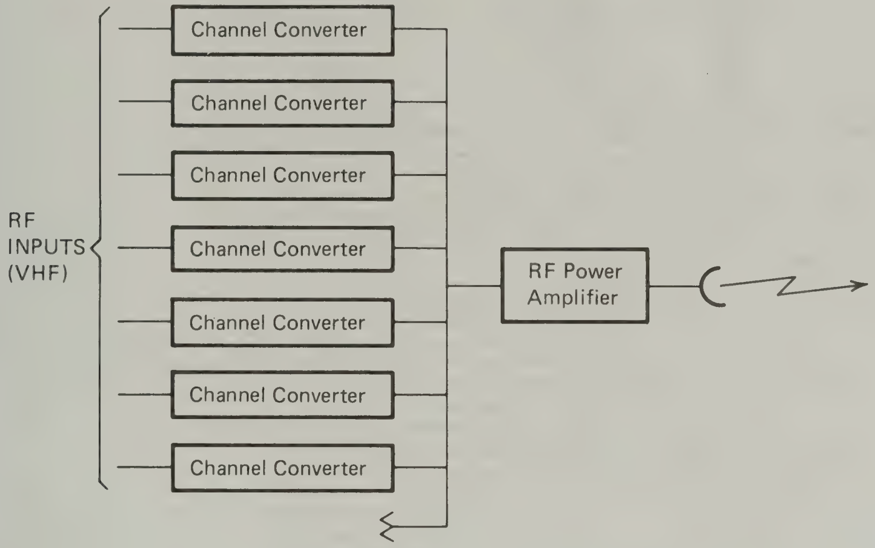

RF
INPUTS
(VHF)
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
RF Power
Amplifier

Figure 22-4 Low Power AML Microwave

General Discussion

Figure 22-4 shows a basic low-power AML installation equipped for seven channels. Note that for those television signals delivered as video/audio information, we must provide an RF modulator before we can apply that signal to the AML equipment. We cannot heterodyne any satellite or single-channel microwave-delivered signals and avoid the demod/remod process because they were initially frequency modulated and are not compatible with the subscribers' television receivers.

In the case of television signals that were already at RF and amplitude modulated (vestigial sideband), for example off-air signals, we can apply those directly to the AML equipment. We can even heterodyne down an off-air UHF channel (470 to 800 MHz) to a VHF channel (50 to 400 MHz) and apply it directly to the AML system. Note that since all AML inputs are at RF (VHF frequencies), we can easily provide a signal feed to any local cable distribution plant as well as microwave transmission from this location.

In Figure 22-5 we show a basic low-power AML installation equipped for 13 channels. We also show an RF feed (at VHF frequencies) to a local cable plant from this same installation, derived through a directional-coupler-combining network.

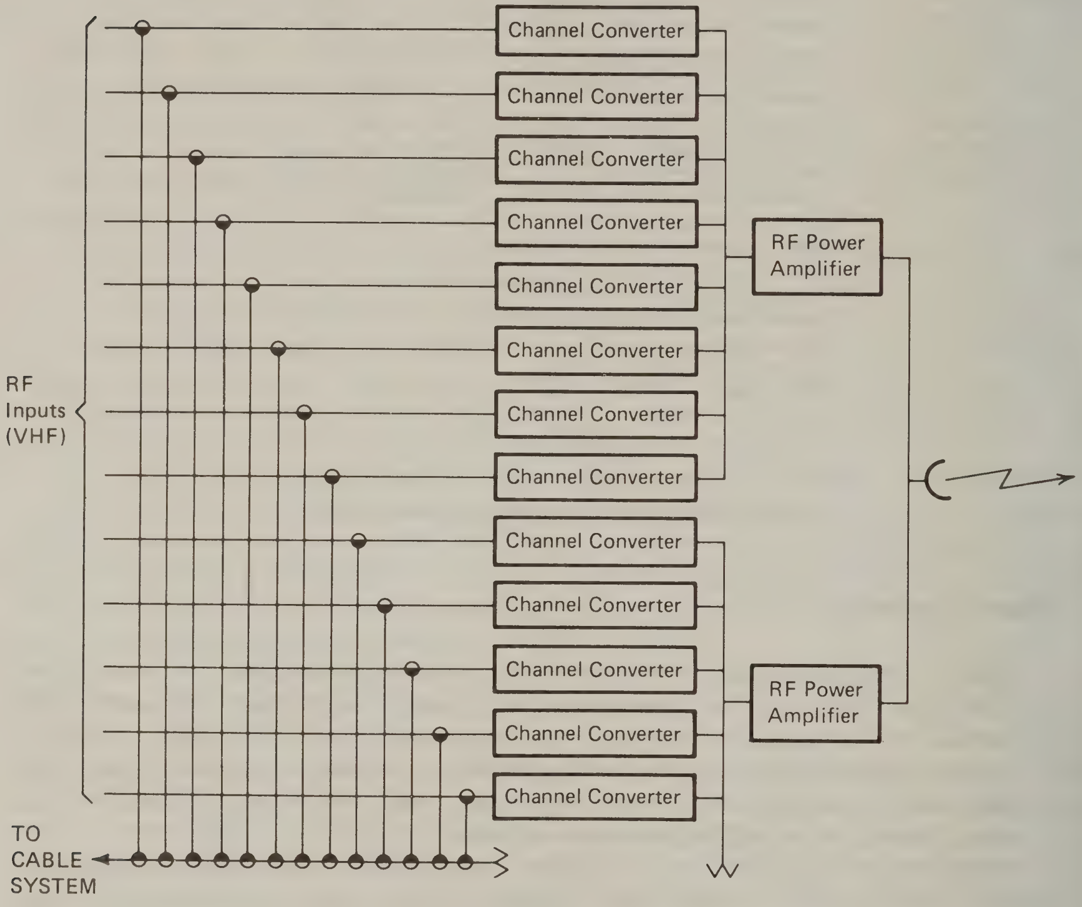

Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
Channel Converter
RF Power Amplifier
RF Power Amplifier
RF Inputs (VHF)
TO CABLE SYSTEM

Figure 22-5 Low Power AML Microwave

In Figure 22-6 we show a basic high-power AML installation. Since an RF amplifier is required for each television signal transported it does not matter if there are 5, or 8, or 31 channels involved. The configuration shown in Figure 22-6 would still apply except that more equipment would be required.

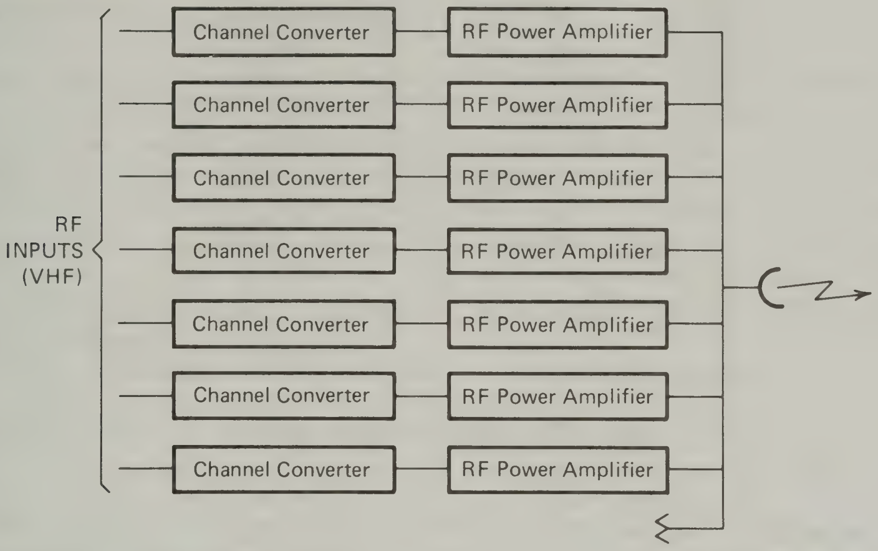

RF
INPUTS
(VHF)
Channel Converter
RF Power Amplifier
Channel Converter
RF Power Amplifier
Channel Converter
RF Power Amplifier
Channel Converter
RF Power Amplifier
Channel Converter
RF Power Amplifier
Channel Converter
RF Power Amplifier
Channel Converter
RF Power Amplifier

Figure 22-6 High Power AML Microwave

All the capabilities of power splitting and diplexing of many channels onto a single antenna feed are available just as they were in the case of the single-channel equipments.

In both the low- and high-power AML applications the microwave receivers are identical. And, as we stated earlier, there is no demodulation process involved. A local oscillator is heterodyned against all incoming microwave frequency carriers and thus all these carriers are translated (converted) back down to their original VHF frequencies. Quite obviously the AML receiver is a broadband device and thus does introduce intermodulation distortion as well as noise. By careful equipment design and providing adequate RF input signal levels to each receiver, the AML system intermodulation and noise contribution can be held to quite acceptable levels.

Figure 22-7 shows an AML receiver with two local off-air channels optionally added. Note that when television signals are added to an AML microwave transmission system, although new equipment is required at the transmitting site for each channel added, nothing at all need be added and no readjustment need be made at any AML receiving locations.

The output of an AML receiver presents all transported television signals at VHF frequencies and at suitable RF levels to directly feed these signals into conventional coaxial cable distribution plant. It is also practical, if desirable, to insert additional signals at this point before feeding the cable distribution system (see Figure 22-7). Such signals might be strong local off-air broadcast stations, for example, or unique pilot carriers for automatic control of local cable plant amplifiers.

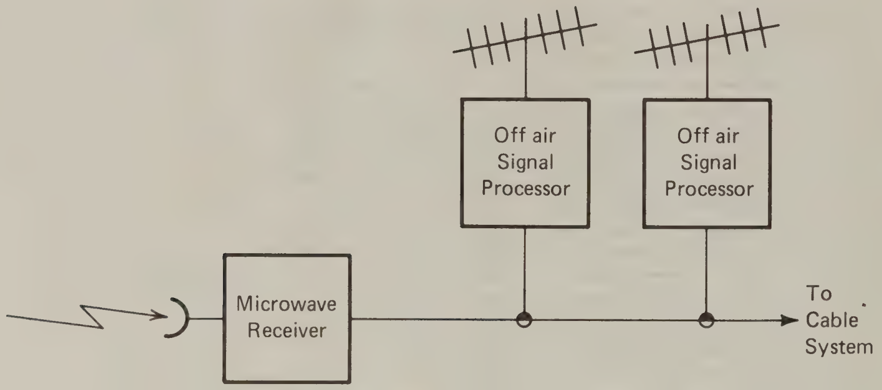


Figure 22-7 AML Microwave Receiver

This might reduce the number of AML channels required and could also provide some limited continuity of television service to subscribers in the unlikely event of a total or catastrophic microwave system failure.

Technical Comparisons of Low and High Power AML

In end-to-end system performance, if path engineering has been carefully done, there is no difference at all between low power and high power. It is obviously more difficult to produce high fade margins with lower RF power available, particularly in multi-path applications. Sometimes this can be overcome simply by specifying larger antennas with higher gain.

The high-power equipment is a bit more redundant since the failure of any RF power amplifier means the loss of only one television channel. In the low-power configuration, up to eight signals can be affected by each power amplifier. This can be offset with special accessories that automatically switch to a spare klystron though this sophistication reduces the cost advantage of lower-power equipment.

The high-power equipment takes more space, consumes more primary power, and generates more heat. Both types should really be installed in controlled air-conditioned environments both to prolong operational life and to improve frequency stability. Both equipments work well and have found quite wide, general acceptance in the CATV industry. In examining any microwave installations, the cost of any required demodulators or modulators for interface with the remainder of the system should be included.

All microwave systems in this country require licensing by the FCC. And microwave equipments must have FCC-type acceptance before they can be placed in service. Licensed microwave transmitters can only be serviced by individuals holding a valid radiotelephone operator's license granted by the FCC.

Practical Considerations of Microwave

When microwave distribution is included in or added to a CATV operation, it introduces a new level of sophistication. The required test equipments, regulatory considerations, and possibly some unfamiliarity on the part of present staff can all be intimidating. But todays solid-state equipments are remarkably trouble free and the technology itself is well within the capability of most CATV technicians. Most problems develop in microwave installations during the construction phases. The people who are most expert and generally available for work on towers are not necessarily, perhaps not even usually, experienced or knowledgeable about waveguide and parabolic antenna installation, and this can introduce problems.

The actual mechanical installation is only an initial phase, however, and if done well, very rarely will the system develop mechanical problems. The CATV operator installing microwave might be well advised to contract out the specialized handling and installation of all waveguide and antennas and should definitely consider final antenna orientation as a contracted effort also. Most microwave suppliers will provide such services, and usually their personnel will help foster understanding and familiarity with the equipments and with the system adjustments for the purchaser's staff at the same time.

Interfacing Microwave with Cable Plant

There are general similarities between microwave systems and coaxial cable plant and it is necessary to recognize them. Consider an AML transmitting facility, either low or high power, feeding several receiving locations. The microwave receivers themselves, like their counterpart cable amplifiers, are broadband in nature. At the receiver which feeds RF (VHF) to the distribution cable plant there is no available control or adjustment for each individual RF carrier, just as there is not in a cable amplifier.

The entire microwave link, including antennas and antenna waveguide feeds, is broadband beyond the point where the individual outputs of the channel converters are combined. This is analogous to the cable system head end. Here individual channel-processing equipments are employed, their RF outputs are all combined, and these are then applied to a coaxial cable with subsequent broadband amplification provided as necessary. In the case of the cable system, the last point where individual RF carriers could be accessed and adjusted was in the head end processing equipment before signal combining had been done.

In the AML microwave equipment, the last point where individual RF carriers could be accessed and adjusted was in the channel converters before signal combining had been done. This can be somewhat confusing in trouble analysis when both cable plant and microwave are involved.

Consider a conventional cable system head end feeding a single distribution cable. The individual RF carriers were all combined, at which point the system became broadband in nature, and applied to the cable plant. During the initial system adjustment each head end signal processor was individually adjusted for proper input to the distribution system. The combined signals may all have been set to have the same amplitude at the head end output point, or they may have been "tilted," that is, they may have been set at varying amplitudes to create a tilted head end output.

Let us assume that at some subsequent time the first cable section sustains some mechanical damage, a cable kink from a falling tree branch, perhaps. This introduces an irregularity into the cable and could create a distortion in cable frequency response. Although the head end output signal levels remained constant we might find improper signal levels at the first amplifier input. Suppose we found that Channel 7 and 8 were both 3 dB lower than all the other signals at this point.

Since this is the first amplifier location we could simply go back to the head end and raise the output level of the Channel 7 and 8 signal processors alone until the input to the first amplifier was correct. This would mask the problem and offset the cable fault and the system might even operate satisfactorily.

Now consider this same situation but this time with the head end output divided equally to feed signal into two individual distribution cables. Given the same mechanical damage to one of the cables which we experienced before, we would eventually find the same 3 dB input level discrepancy at the first amplifier on the damaged cable route. But now, if we simply readjusted the Channel 7 and 8 signal processors alone at the head end, we would distort the normal signal input to the first amplifier on the undamaged cable route. There is no single channel adjustment that can reconcile proper signal levels in both distribution systems.

This same relationship between single-channel adjustments made before signal combining has been done, and broadband operations after combining has been completed, exists in microwave systems and it can be a bit confusing in recognizing or correcting system problems.

Just as a kink or deformation of a coaxial cable can distort the frequency response of the cable, so will a mechanical distortion of the microwave waveguide. At 12 GHz we frequently utilize elliptical waveguide for all or part of the antenna feed line. This is a semi-flexible type of waveguide and is easily kinked if it is abused during installation.

Examine Figure 22-5 for a moment. Not shown in the drawing would be the head end equipments providing RF (VHF) inputs to both the AML channel converters and, through the directional coupler-combining network, to the local distribution cable plant also. Note that it is possible, by adjusting output levels on individual head end equipments, to establish any particular RF input to the local cable plant that might be desirable. But it must be remembered that if such adjustment of any individual carrier is made, the impact on the AML channel converter output level and thus the RF (VHF) output of all AML microwave receivers will also be affected. A compensating readjustment of the AML signal level may be necessary.

It is essential that we understand which sections of a system are actually broadband in nature and when individual single carrier adjustments are available, and the interaction of any single carrier adjustment on all other sections of the overall system cannot be ignored.

Lightwave Transmission

Although we have not discussed lightwave transmission as yet (it begins in the next Chapter), since this section is devoted to signal transportation systems alone, and since lightwave systems have a very real capability in this respect, we will briefly introduce light in this Chapter. The terms employed and the modulation techniques will become quite clear to the student after he or she has gone a bit farther in the book.

The transportation of signals from one single point to one or more discrete points is the subject of this Chapter, not the direct extension of such signals into the distribution plant which actually serves the subscribers homes. In transporting signals, it is anticipated that those signals will be applied to some extensive distribution plant, be it coaxial cable alone, or a hybrid combination of optical fiber and coaxial cable. Such a distribution network obviously contributes significant noise and distortion, thus the transportation system must be designed very conservatively so as to make small or nominal contributions of same.

It is also anticipated, in transporting signals, that the receiving terminals are limited in number. By that we mean that unusual or expensive treatment of any single signal can be tolerated, since such costs would be borne by a number of subscribers and not by any single subscriber station alone.

Then transportation systems are conservatively designed to be as transparent as possible and are not necessarily cost effective. The quality of transmission is primary in these applications, and the cost is definitely secondary.

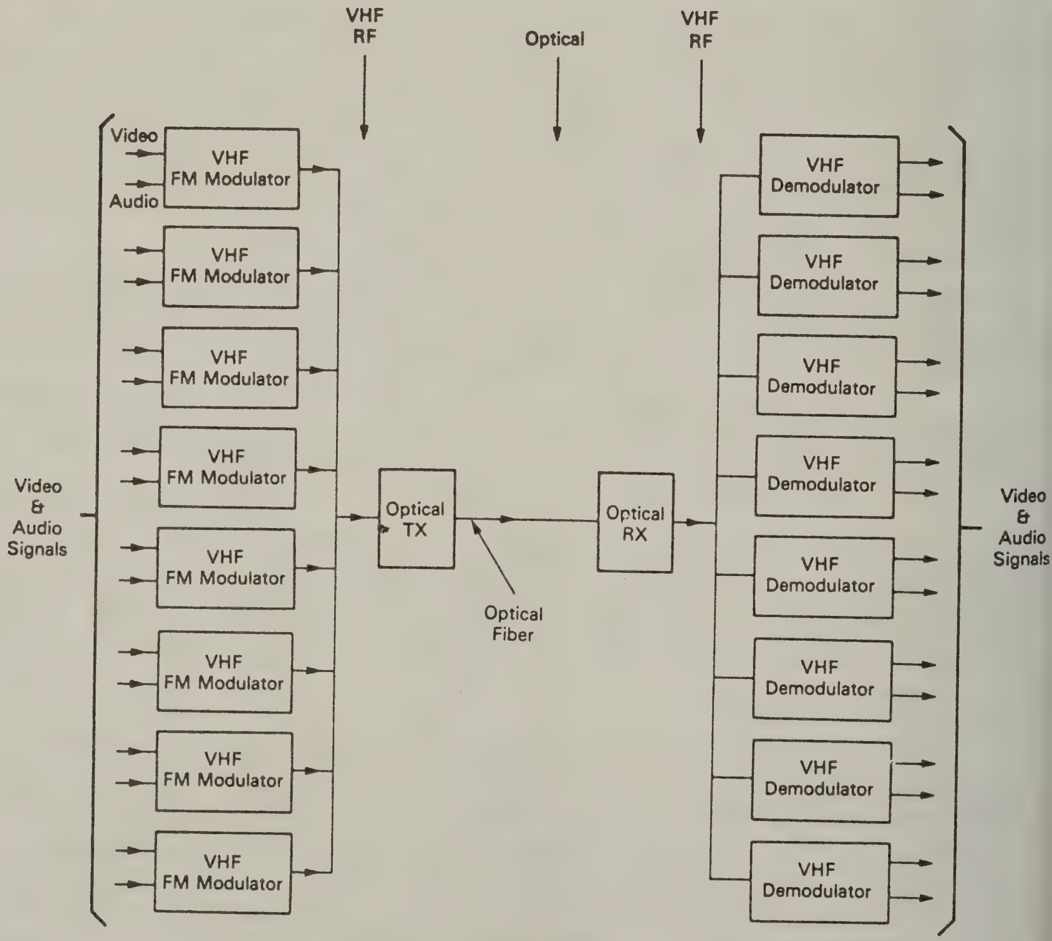
The most common utilization of lightwave transmission to date has been digital modulated and multiplexed for data or telephone transmissions between two discrete terminals, as in Telephone trunking between Central Offices or switches for example, where a large number of relatively narrow bandwidth circuits are provided. But there is nothing inherent in lightwave transmissions on optical fibers that precludes their use as a broadband medium, using frequency division to multiplex a number of broader band, analog and/or digital signals, such as television channels.

This is the way lightwave transmission has been widely used in the Cable Television business, at least when optical fibers and lightwaves have been applied to the distribution in Cable Television systems. In this application, the distribution system, although we may think of optical fibers as an entirely new technology introduced into coaxial broadband systems, in one respect the fiber plus coax presents a very natural extension of the transmission bandwidth, just as we have quite naturally transitioned from 300 to 500 to 800 or so Megahertz in conventional coaxial cable systems.

The next few chapters deal with light, it's generation, modulation, and transmission properties, and it's inclusion in conventional coaxial cable distribution systems, but there are purely transportation applications as well.

As a signal transportation facility, a lightwave link can be considered in much the same manner as we have utilized microwave transmissions. Microwave links can also be digitally modulated, and this modulation can digitally combine or multiplex several individual signals or circuits if required. So can lightwaves on optical fibers.

Microwave systems also present a relatively broad baseband for transmission use, whereby many television signals can be analog in nature, and can employ either amplitude, frequency, or digital modulation, and are separated by frequency division. Any single signal could be digitally modulated by itself, and then applied along with AM or FM signals to the microwave baseband. So can lightwaves on optical fibers be applied.



VHF RF
Optical
VHF RF
Video
Audio
VHF FM Modulator
VHF FM Modulator
VHF FM Modulator
VHF FM Modulator
VHF FM Modulator
VHF FM Modulator
VHF FM Modulator
VHF FM Modulator
Video & Audio Signals
Optical TX
Optical Fiber
Optical RX
VHF Demodulator
VHF Demodulator
VHF Demodulator
VHF Demodulator
VHF Demodulator
VHF Demodulator
VHF Demodulator
VHF Demodulator
Video & Audio Signals

Figure 22-8 Analog Video Transmission

Light, and the transmission of lightwaves, is a subject which warrants in-depth treatment and we will subsequently do so, but suffice it here to say that lightwave systems, operated on an analog, broadband basis or on a digital modulation basis, is a viable alternative for Super-Trunk cable or microwave transportation transmission.

In Figure 22-8 we show a transportation system that utilizes analog signals and frequency division multiplexing to carry a multiplicity of television signals from one point to a single hub or perhaps to a few hubs, for extension to coaxial or hybrid coaxial/fiber distribution plant. Note that the modulation of individual carriers is FM, to derive the FM improvement factor, but this system requires re-modulation of all signals at the receiving terminal, which is assumed to be a distribution hub.

This re-modulation is necessary if we are to carry the video carriers on the distribution plant as amplitude modulated or AM, as conventional Cable Television distribution systems do. If we carry them as FM signals, then we must process those signals at each and every subscriber terminal serviced, to ensure the direct interface to the subscriber owned television receiver, which is the end device served.

Quite obviously the modulation in the lightwave transmission system could be AM also, and this might compromise transmission quality somewhat, but it would certainly reduce transportation costs. But the cost of transportation systems, borne by many subscriber stations, is a secondary factor, as we have pointed out earlier.

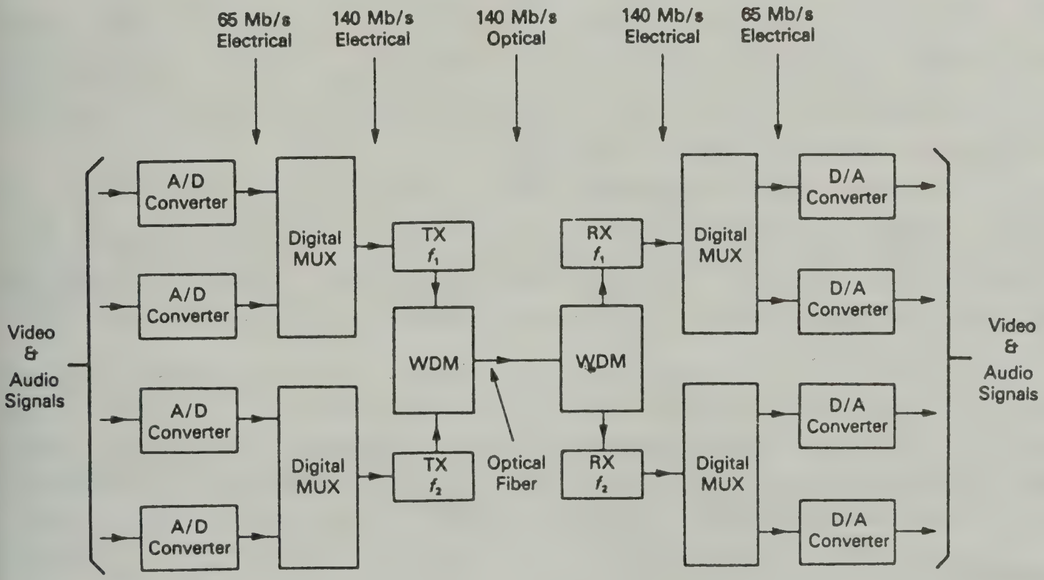

65 Mb/s Electrical
140 Mb/s Electrical
140 Mb/s Optical
140 Mb/s Electrical
65 Mb/s Electrical
Video & Audio Signals
A/D Converter
A/D Converter
A/D Converter
A/D Converter
Digital MUX
Digital MUX
TX f_1
TX f_2
WDM
Optical Fiber
WDM
RX f_1
RX f_2
Digital MUX
Digital MUX
D/A Converter
D/A Converter
D/A Converter
D/A Converter
Video & Audio Signals

Figure 22-9 Digital Video Transmission

A digital transportation application is shown as Figure 22-9. Here we show digital modulation of each individual television signal to a 65 Megabits per second (Mb/s) pulse stream through the use of analog to digital converters, shown as A/D Converters in the drawing. We combine two such pulse streams with a digital multiplexer into a single signal at a 140 Mb/s rate. This signal is used to modulate an optical transmitter, as the figure shows.

We have complicated this system somewhat by applying two individual lightwave carriers, each modulated with a 140 Mb/s signal, and each with a transmission capacity for four television signals, onto a single optical fiber. We do this with a technique called *wavelength division multiplexing* and with a unit designated in the drawing as WDM. Later in the book we will expand on this technique.

Note that at the receiving site the output is four individual television signals as audio and video. As in the FM modulated analog transportation link, we must add an AM modulator to each television signal, and all of this processing....analog to digital....digital to analog....and finally AM modulation, is relatively expensive, but the quality of transmission can be excellent.

Using optical fibers, there is no Federal licensing as is required with microwave systems, and there are no cascaded amplifiers as in Super-Trunking. As we develop lightwave technology, the student will clearly see transportation possibilities and practicality.

Transportation Engineering

All of the transportation systems discussed here are capable of system designs which produce an unusually high quality of transmission. At least the transmission quality can be better than that provided in a conventional coaxial cable distribution system. Particular attention is given to operating levels and equipment quality for transportation, and this is quite understandable.

We propose signal transportation links or systems for the delivery of a multiplicity of signals to subsequent coaxial or fiber/coaxial distribution plant. We know that the cumulative transmission performance of the distribution plant will be somewhat severe in nature. Then the transportation system, whatever its nature may be, must contribute a minimum of noise and distortion if the end result to subscribers is to be acceptable.

Thus transportation systems are conservative in transmission design and are not, as a general rule, particularly cost effective in themselves. The name of the game is to make all signal transportation links as transparent for noise and distortion as possible, so as to allow contributions from the subsequent distribution plant to be tolerable in the overall transmission performance.

Summary

The decision as to the use of microwave, Super-Trunk, or lightwave transmission systems for signal transportation is more a business than an engineering decision, and would be made on the basis of technical performance and cost effectiveness.

Chapter 23

Introduction to Light

In this day and age of high pressure marketing, acronyms, and technical "buzz words," and the general public enchantment with every new technology, lightwave transmission fits in beautifully. It has a impressive mystique all its own with connotations of scientific significance and an intriguing vocabulary of terms like laser, Megabit, modal dispersion, and the like. An individual speaks, a light blinks, and perhaps hundreds of miles away another person hears the speakers voice. Surely, by any standard of general public measure, lightwave transmission is "high tech."

But people have been communicating through "lightwave transmissions" since time immemorial. Before the blinking semaphore of ships, before Longfellow's "One if by land, two if by sea," human beings used fire to guide the cavemen home from the hunt. Even the ubiquitous traffic light, which regulates so much of our everyday movement, depends upon the transmission of light.

But is lightwave transmission definitive?

We can measure a gallon of water with great precision, we can measure the flow of water, the pressure and temperature, etc. We can measure electricity and its flow, and the pressure producing that flow, and we feel confident and comfortable with the terms and results of such activities.

Can we define light nearly as well, and are we as confident of the results?

Theories of Light

Mankind has long been obsessed with light, exactly what it is, how it is produced, and how it travels through space. Some of these questions remain unanswered because science has not offered, as yet, a complete theory of light. Nevertheless, a great deal has been learned about light in the last three centuries.

Philosophers and scientists have held six major theories concerning the nature of light over the last 3,000 years. These are known as the tactile theory, the emission theory, the corpuscular theory, the wave theory, the electromagnetic theory, and the quantum theory.

The Quantum Theory

In 1900 the German physicist Max Planck suggested that light was emitted and absorbed as a succussion of bundles of energy which he called "quanta." He suggested that the amount of energy contained in each "quanta" was proportional to the frequency of the light. Albert Einstein extended Planck's idea and suggested that light not only was emitted and absorbed as individual units, but that it actually traveled in the form of these units, later called "photons." In 1905, applying this theory, Einstein explained and verified the photocell effect.

More recently, contributions by many scientists have made it possible to explain almost all behavior of light by means of the quantum theory, which avoids the purely mechanical description of light.

Light cannot be thought of as either a system of waves or a system of particles. Sometimes it acts as waves and sometimes as particles, but neither explanation can be considered complete in itself. When light interacts with matter, it exhibits wave-like or particle-like properties, depending upon the nature of the interaction itself.

One Definition of Light

Although it is interesting and provocative to study light in some detail, when we attempt to apply it to practical ends as in transmission systems for example, we are obliged to resolve all the questions and develop and apply an appropriate and acceptable definition of light itself.

Light is kinetic energy, that is, energy associated with movement, and as such may be measured in units of energy such as joules (J) or electron volts (eV). The unit of light energy is the photon, which is a massless bundle of electromagnetic energy. The term massless is used to distinguish photons from objects that have measurable mass at rest, such as atoms or electrons.

A photon cannot be captured and put on a scale and weighed. When a photon is "caught," such as when light is absorbed by your skin for example, the photon ceases to exist as such. Its energy is converted to some other form of energy, for example, thermal energy or heat. When sunlight falls upon your skin it feels warm. It actually is warm because light energy has been converted to heat and you feel the rise in temperature.

Photons exist as such only when they are moving. They move at the rate of $3.0 \text{ X } 10^8$ meters per second which is the speed of light in a vacuum, and usually somewhat slower in other material.

Alternating Waves

Like radio and sound waves, light is electromagnetic energy which travels in a wavefront. Thus light can be identified within the general electromagnetic spectrum of alternating waves.

One complete sequence of values of any electromagnetic alternating wave starting at zero, increasing to a maximum value, decreasing to zero, decreasing to a minimum value, and increasing to zero again is called a cycle. (See Figure 23-1.) Since the instantaneous value of the wave is changing, some period of time is required for a complete sequence of changes or for one full cycle to occur. This time period is universally referred to one second.

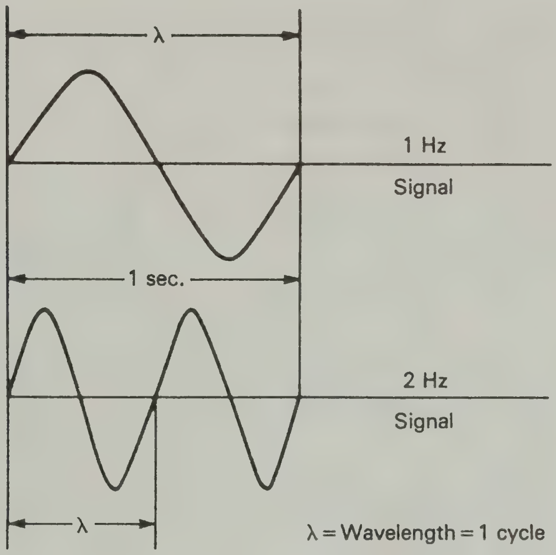


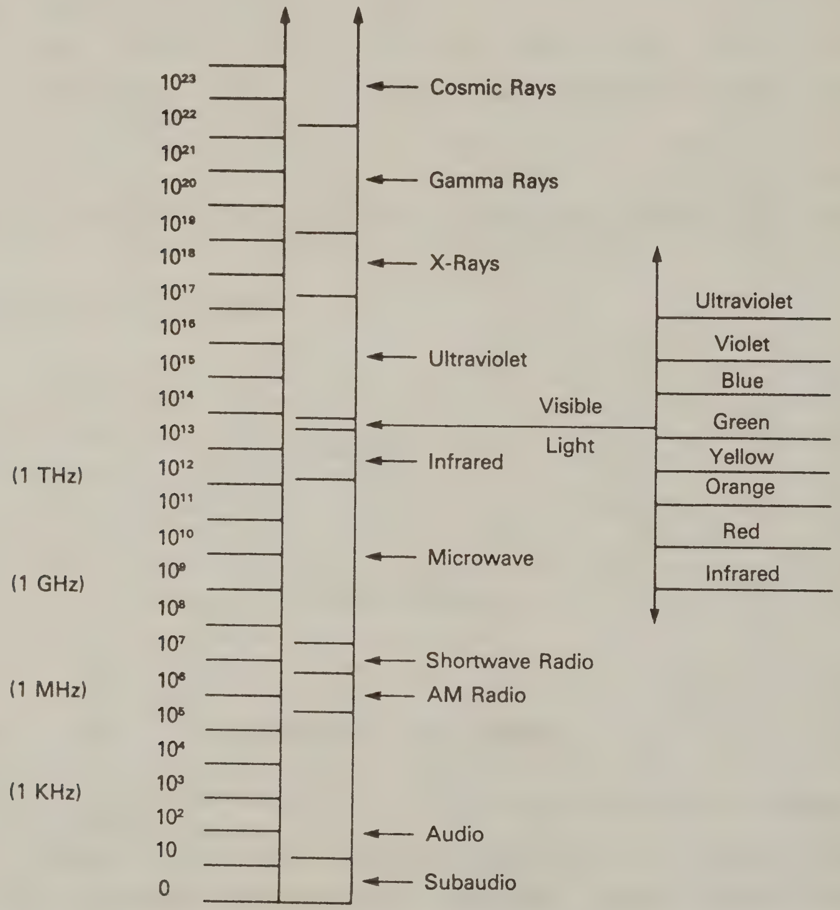
Figure 23-1 Wavelength

The number of cycles that occurs in one second can be called "cycles per second" which was, for a long time, the International standard reference of frequency. The term "cycle" has been replaced by the term "Hertz," named for the German physicist Heinrich Hertz. The Hertz is interchangeable with the older term cycle and the "cycles per second" is now stated as "Hertz per second."

Figure 23-1 shows both a 1 Hz and a 2 Hz signal. Note that the time period for both signals is the same, one second, but two full cycles have occurred in the 2 Hz signal. As a point of reference, in the United States, most commercial power is alternating current (AC) and is at a 60 Hz rate, that is, 60 full cycles occur every second.

Electromagnetic Spectrum

The electromagnetic spectrum is shown in Figure 23-2 with all notations in units of frequency, cycles or Hertz per second. The relationship of lightwave frequencies and spectrum to other perhaps more familiar transmission disciplines is clearly shown. This notation becomes quite cumbersome when we approach higher frequencies. As we address the lightwave region of the spectrum, the frequencies involved are very high indeed and must be designated in Terahertz which is 10^{12} Hertz, a very large unit.



10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
(1 THz) 10^{12}
10^{11}
10^{10}
(1 GHz) 10^{9}
10^{8}
10^{7}
(1 MHz) 10^{6}
10^{5}
10^{4}
(1 KHz) 10^{3}
10^{2}
10
0
Cosmic Rays
Gamma Rays
X-Rays
Ultraviolet
Visible
Light
Infrared
Microwave
Shortwave Radio
AM Radio
Audio
Subaudio
Ultraviolet
Violet
Blue
Green
Yellow
Orange
Red
Infrared

Figure 23-2 Electromagnetic Spectrum

Many optical mechanisms, even some higher frequency electrical mechanisms such as waveguides, are more directly associated with or related to wavelength rather than frequency. It becomes more convenient and practical to use wavelength when working with lightwaves and some microwave frequencies as well.

At higher radio frequencies, devices such as antennas, waveguides, and resonant cavities and transmission lines involve physical dimensions directly relating to wavelength, and this is even more pronounced in lightwave technology.

Frequency-Wavelength Relationship

Electromagnetic waves, including lightwaves, travel in a vacuum at a speed of 186,280 miles per second. It is often more convenient to state this velocity in metric terms, and the figure 3×10^8 meters per second is often used for the speed of light in rough calculations, although the term 299,793,000 meters per second is more precise.

The distance that the wave would travel while experiencing one full cycle is called the *wavelength*, and is generally denoted by the Greek letter lambda (λ). Wavelength may be stated in units of measure of length, providing that the velocity of propagation is known, of course. We must realize that in different media, in free space or in glass for example, the speed or velocity of propagation will be different for the same identical frequency.

For example, we can easily calculate the wavelength of a 60 Hertz wave traveling in space by dividing the velocity of propagation (186,280 mile per second) by the frequency in Hertz (60 Hz). Thus the wavelength (λ) of a 60 Hz signal in space would be 3,104.66 miles.

At very low frequencies such as the 60 Hz in our example, such calculations may be somewhat academic, but at higher frequencies they certainly are not. At radio broadcasting frequencies on the order of 1,000 kHz (1 million Hertz or 1 Megahertz), for example, amplitude modulated (AM) radio stations often use vertical steel towers as radiating quarter-wave antennas. In such cases it is necessary to determine the wavelength in feet or meters to establish the required height of the tower itself. For the example of a station broadcasting on 1,000 kHz, the calculations would be as follows:

Convert the velocity of propagation (186,280 miles per second) to feet per second (983,560,000 feet per second).

We simply divide this figure by the frequency in Hertz to establish the wavelength in feet.

Dividing this figure by four gives a quarter-wavelength in feet, which would be the tower requirement in feet for a quarter-wave antenna.

$$\frac{983{,}560{,}000}{1{,}000{,}000} = 983.56 \text{ feet (1 wavelength at 1,000 kHz)}$$

$$\frac{983.56}{4} = 245.89 \text{ feet (1/4 wavelength at 1,000 kHz)}$$

Hence the tower must be 245.89 feet in height if it is to function effectively as a quarter-wave antennas at this frequency.

There are, of course, other simple conversion formulas.

For wavelength in centimeters, given frequency in Gigahertz :

$$\text{Wavelength} = \frac{30}{f\ (\text{GHz})}$$

For wavelength in meters given frequency in Megahertz :

$$\text{Wavelength} = \frac{300}{f\ (\text{MHz})}$$

In both of these examples, the term for velocity of propagation of the wave is related to 3 X 10^8 meters per second, and if greater precision were necessary, the figure 299,793,000 could be employed.

Velocity of Propagation

The velocity of propagation, as we have mentioned earlier, is a factor in determining the wavelength of a wave of course, but it will be different in different media or materials for any wavelength of a given frequency. For example, a lightwave of a given frequency will travel at a different speed in glass than it will in air, even though the frequency of that lightwave remained unchanged. Within the same media, waves of different frequency will travel at different speeds also, thus they will have different wavelengths. Lightwaves travel at slightly different speeds in air than in a vacuum, as in free space for example. For the purposes of our discussions, however, we will assume the velocity of lightwave propagation to be the same in both media, air and in a vacuum.

Use of the term *wavelength* as a common reference may be unfamiliar to many readers, but it is by no means new. Radio amateurs, for example, have always referred to sections of the spectrum in terms of wavelength. They commonly refer to the 80 meter band for 3.5 to 4.0 MHz or the 10 meter band for the frequencies of 28.0 to 29.7 MHz. Being higher in frequency, they are in fact shorter in wavelength than conventional broadcast radio, thus the term "shortwave." At even higher frequencies, in the microwave range for example, we find common reference to the band 30,000 to 300,000 as the millimeter microwave band.

At lightwave frequencies which are designated in terahertz (one terahertz is one trillion Hertz per second), it is much more convenient and practical to use wavelength exclusively, but we must specify the transmission media since it will affect the velocity of propagation, and thus the wavelength.

In working with frequency we use conventional prefixes such as kilohertz (10^3) for a thousand Hertz per second, Megahertz (10^6) for a million Hertz per second, and Gigahertz (10^9) for one billion Hertz per second. In denoting lightwave wavelength we also use prefixes, but they diminish in scale as the wavelength gets shorter, which is the same as the frequency getting higher.

Wavelength Units

In length measurement, with the meter (39.37 inches) as a point of reference, we use centimeter for hundredths of a meter (10^{-2}) and millimeter for thousandths (10^{-3}). At lightwave frequencies, where wavelengths are very short indeed, these units are not small enough.

We use the micron (u) to denote a millionth (10^{-6}) of a meter, but in more common usage, and for the same dimension, is the micrometer (um), which is also (10^{-6}) meters. The two terms are interchangeable. For billionths of a meter (10^{-9}) we use the nanometer (nm). The picometer (10^{-12}) is one trillionth, and the femtometer (10^{-15}) is one quadrillionth, but these terms are not frequently encountered.

It is interesting to note, and gives some perspective to these terms, that there are 25.4 million nanometers or 25.4 thousand micrometers, in one inch.

If we specify the transmission media as air or a vacuum, then the wavelength for any frequency may be calculated of course. This means that we can state the frequency and the wavelength for the electromagnetic spectrum, and we present that as Figure 23-3.

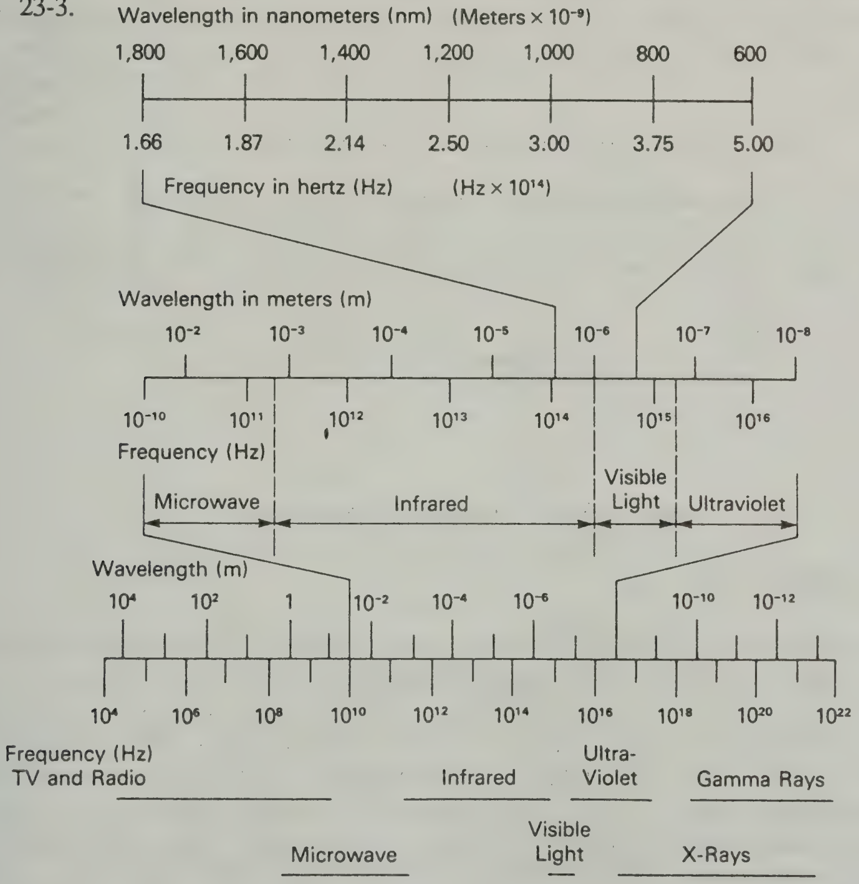

Wavelength in nanometers (nm) (Meters × 10⁻⁹)
1,800
1,600
1,400
1,200
1,000
800
600
1.66
1.87
2.14
2.50
3.00
3.75
5.00
Frequency in hertz (Hz) (Hz × 10¹⁴)
Wavelength in meters (m)
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻¹⁰
10¹¹
10¹²
10¹³
10¹⁴
10¹⁵
10¹⁶
Frequency (Hz)
Microwave
Infrared
Visible Light
Ultraviolet
Wavelength (m)
10⁴
10²
1
10⁻²
10⁻⁴
10⁻⁶
10⁻¹⁰
10⁻¹²
10⁴
10⁶
10⁸
10¹⁰
10¹²
10¹⁴
10¹⁶
10¹⁸
10²⁰
10²²
Frequency (Hz)
TV and Radio
Infrared
Ultra-Violet
Gamma Rays
Visible Light
Microwave
X-Rays

Figure 23-3 Electromagnetic Spectrum

Within this spectrum, bands of frequencies where waves have common characteristics are often referred to in generic terms such as audio frequency is, the radio spectrum, and the light spectrum, for example. The radio spectrum is generally accepted to include the frequencies between 8 kHz and 300 GHz.

We present Figure 23-4 as the lightwave frequency spectrum, but note that not all lightwave frequencies are visible to the human eye. We have further denoted the "visible" spectrum in Figure 23-4. Also note that different frequencies of visible light denote different colors, and these are also denoted in the figure.

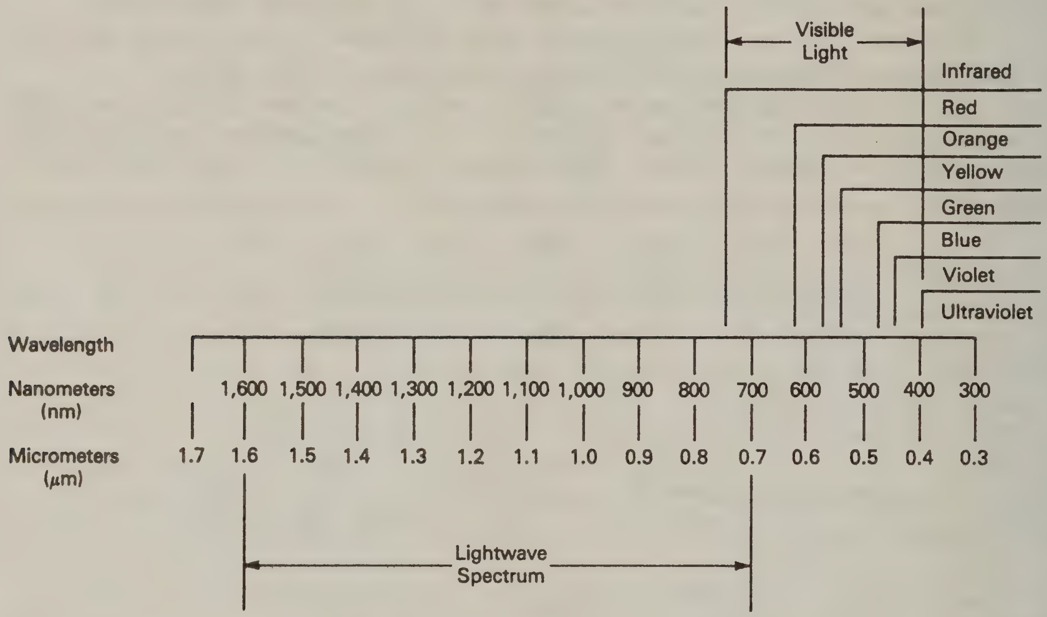

Visible Light
Infrared
Red
Orange
Yellow
Green
Blue
Violet
Ultraviolet
Wavelength
Nanometers (nm)
1,600 1,500 1,400 1,300 1,200 1,100 1,000 900 800 700 600 500 400 300
Micrometers (μm)
1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3
Lightwave Spectrum

Figure 23-4 Lightwave Spectrum

Another Definition of Light

The definition of light in everyday use refers to that region of the electromagnetic spectrum that can be visually perceived by the human eye. This is designated as the visible spectrum of course, and nominally covers the wavelengths between 0.4 micrometers (400 nanometers) and 0.7 micrometers (700 nanometers).

But in the laser and optical communications fields, custom and practice have broadened the usage of the term lightwave to include frequencies in those regions of the electromagnetic spectrum that can be processed with basic optical techniques and mechanisms that may be used in working with the visible spectrum, even though such wavelengths may not be visible to the human eye.

This region is not precisely defined but it is generally held to extend from the near ultraviolet region (approximately 300 nanometers) through the visible wavelengths and into the mid-infrared region (approximately 3,000 nanometers).

Properties of Light

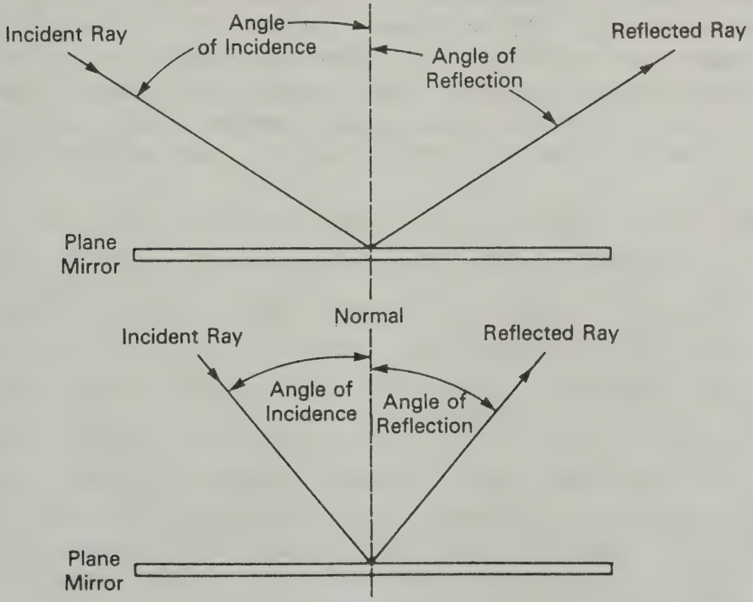
Like all electromagnetic radiation, light is a form of energy and can be converted into other forms of energy. When light strikes certain materials, those materials give off electrons. This transfer of light energy to electrical energy is called the *photoelectric effect.* In certain substances, light can also produce chemical effects.

We can address light purely from the point of view of its illuminating characteristics, or we may address it as a form of energy in applications that utilize light as a medium for transferring energy such as in telecommunications systems.

There are a number of properties of light which may or may not have a direct relationship in telecommunications applications, but which will expand our basic understanding of lightwaves. We will present a number of figures and some brief explanation of each to broaden this understanding.

Reflection

One of the most familiar properties of light is its ability to be reflected. As shown in Figure 23-5, the incident light rays, the reflected rays, and the normal (a line perpendicular to the reflective surface) are all in the same plane.



Incident Ray
Angle of Incidence
Angle of Reflection
Reflected Ray
Plane Mirror
Normal
Incident Ray
Reflected Ray
Angle of Incidence
Angle of Reflection
Plane Mirror

Figure 23-5 Reflection

Diffusion

Reflection in many directions is called diffuse reflection and occurs if the irregularities in the reflective surface are about the same size, or are larger than, the wavelength of the lightwave striking the surface.

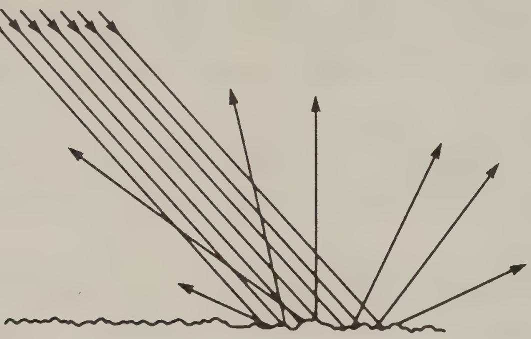


Figure 23-6 Diffusion

White light includes all colors or wavelengths of visible light. If white light illuminates the pages of this book relatively evenly, and the surface of the page is rough with the distribution of the roughness random, very tiny portions of this surface are reflective. The roughness distributes the reflected light in random planes. The paper has no discrete light absorbing qualities and reflects all wavelengths equally well, thus the reflected light appears to be "white" also. The reflected light is widely distributed angularly in a random manner, so white light appears to emanate equally from all parts of the page, and the page visibly appears to be white.

Another simple analysis is the "trick" question, "When the snow melts, where does the white go?" The white, of course, was not a property of the snow. The snow consists of a multiplicity of small, randomly sized reflective surfaces. All wavelengths of light are reflected equally well, and widely distributed angularly as well. If we illuminate the snow with white light, as with the page of the book, all wavelengths emanate equally well in all directions and the snow appears to be white. If we illuminate the snow with green light, it would reflect the green wavelength equally well and would appear to be green, of course.

When the snow melts, all the reflective surfaces disappear and the original surface beneath the snow is exposed. If we illuminate with white light (all the wavelengths of visible light) the light would impinge on whatever surface existed. For example, suppose it was grass beneath the snow. Grass contains a green pigment which absorbs all visible lightwaves except green.

Then all wavelengths other than green are absorbed by the grass, the green wavelength is reflected, and the grass, the original surface beneath the snow, appears to be green to our eyes. Since light is energy, its particles called photons are present in all the wavelengths that impinge on the surface. If only some wavelengths are reflected, the remaining energy must be absorbed by the material or substance of the reflective surface. This energy is converted to heat and in plants and grass, the heat is usefully employed by the process called photosynthesis.

Color Related Terms

A number of terms are employed in talking about color which may add to our understanding of light. As we have seen, color relates directly to different wavelengths of light. Many of these terms are based on the word *chroma*, a noun form of the Greek word *chromo*, which is defined as "a quality of color combining hue and saturation."

The word *chromatic*, for example, defines as "the quality of color characterized by its dominant or complimentary wavelengths and purity taken together. *Monochromatic* is having or consisting of one color or hue" or "consisting of radiation of a single wavelength or a very small range of wavelengths. *Dichromatic* is having or exhibiting two colors or wavelengths. *Monochromatism* is complete color blindness in which all the colors appear as shades of gray."

Refraction

An important property of light is its ability to be refracted. Refraction results from light traveling at different speeds through different media such as air, water, glass, and other transparent substances. When light travels through water, for example, it is abruptly slowed down from a velocity of about 186,000 miles per second to about 140,000 miles per second.

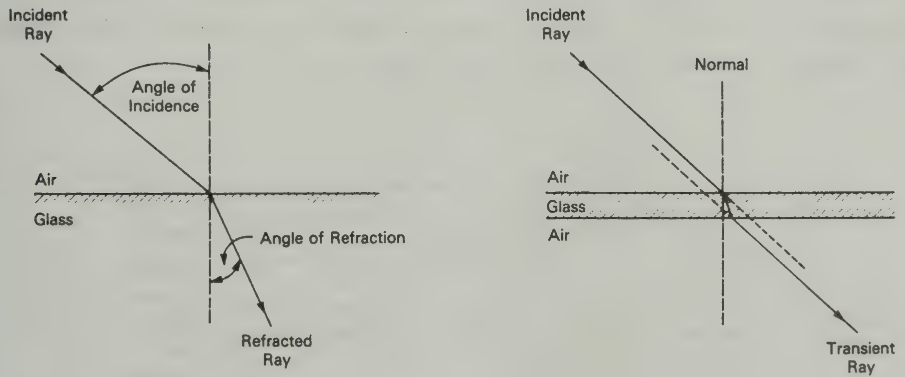


Figure 23-7 Refraction

If a ray strikes the surface of a denser substance at any angle other than 90° it will travel through that substance in a different direction, close to the normal. The new direction is determined by the *index of refraction* of the substances. The index of refraction is the ratio of the velocity of propagation of light in a vacuum, to the velocity of light in that substance.

The index of refraction of light in air is 1.003, thus the speed of light in air is only slightly (about 50 miles per hour) slower than the velocity of propagation in a vacuum. The refractive index of some other common substances is 1.33 for water, 1.51 for glass, and 3.34 in iodine. Clearly, light travels quite a bit slower in glass than in a vacuum or in air.

Refraction accounts for why stars appear to *twinkle*. A star is a point source of light and does not turn "on" and "off," but it appears to do so. As the light from the star enters the earths atmosphere, it is refracted, since air and a vacuum are different medium with different refractive indexes. As the atmosphere changes slightly due to wind currents and the like, the reflective index of the atmosphere changes slightly. The refraction of the light also changes, and the light appears to come from different points or to move slightly, causing the star to seem to sparkle or twinkle.

The light from the moon and planets is refracted in an identical manner of course, and it might be said that the moon "twinkles" also. But the moon is observed as a large object, not as a point of light. The relatively slight movement or refraction is visually imperceptible.

Under certain conditions, light passing through one medium to another will not be refracted at all. Light that is incident normally, that is, that is on a normal plane to the boundary between two media, will pass straight through without being refracted at all.

Dispersion

The process of separating light according to its frequency is called *dispersion.* A prism, for example, dispersing white light by refraction, causes the different wavelengths (or colors) of light to travel in different directions, thus separating them and forming a spectrum as shown in Figure 23-8.

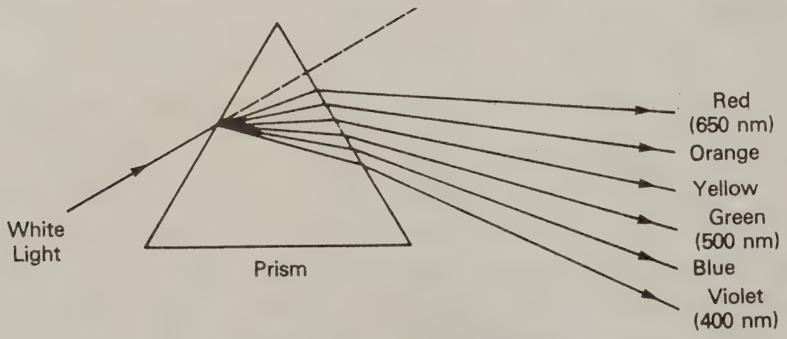


Figure 23-8 Dispersion

Any source of light may produce a spectrum of course, but different sources may produce different spectra. By analyzing the light spectrum of individual stars, scientists have been able to determine the elements present in them, and the relative abundance of those elements.

Diffraction

The term that describes the bending of the path of lightwaves when they pass close to the edge of an obstacle, or through a narrow slit, is called *diffraction*. When a beam of light passes through a narrow slit, it spreads out because of the bending of the lightwaves around the edges of the slit. See Figure 23-9.

Diffraction can be used to separate composite light into individual wavelengths by etching or scoring a number of fine parallel lines closely spaced on an optical surface. The wavelengths that will be diffracted, and thus separated angularly, will be determined by the spacing of the lines and the shape of the etched grooves. Such a device is called a *diffraction grating*.

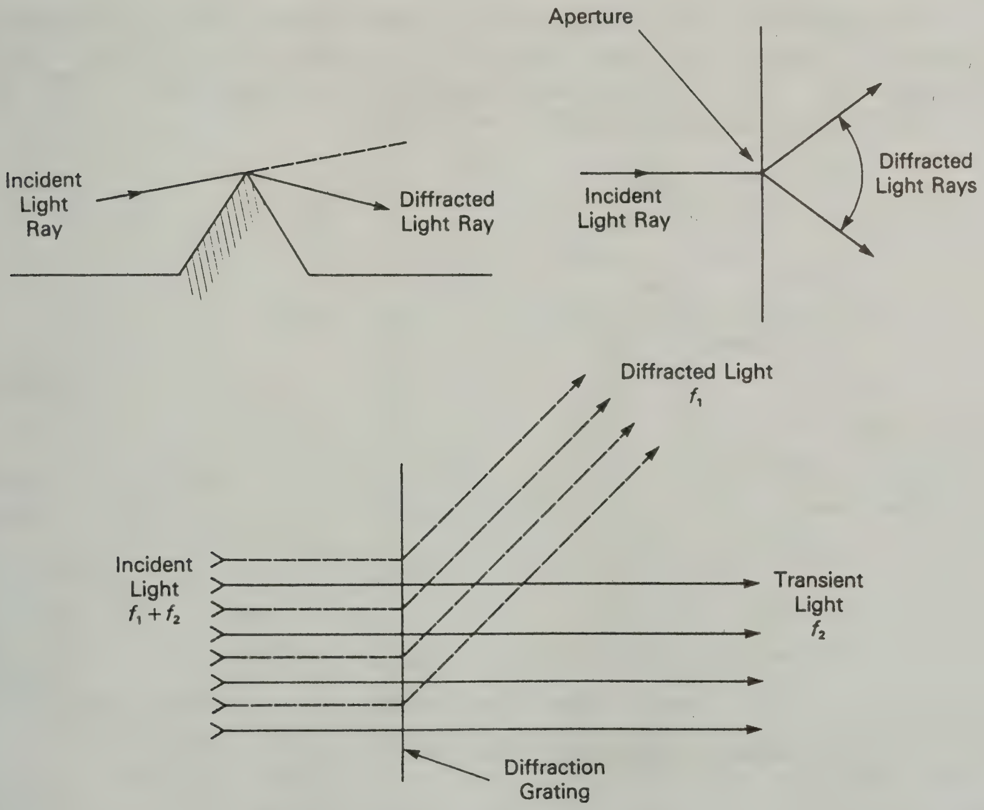

Incident Light Ray
Diffracted Light Ray
Aperture
Incident Light Ray
Diffracted Light Rays
Diffracted Light f_1
Incident Light $f_1 + f_2$
Transient Light f_2
Diffraction Grating

Figure 23-9 Diffraction

Absorption and Scattering

Absorption is a phenomenon whereby light strikes an object and gives up some, or all, of its energy to the atoms of that substance. If the atoms retain that energy, it is converted to heat.

In some substances, the light energy given to the atoms of that substance raise their energy level to the point where they, in turn, emit light. If the light energy so emitted is of a longer wavelength than that of the incident light, the process is called luminescence.

If the emitted light is of the same wavelength as the incident light, then the light is said to be "scattered." Scattering should not be confused with an optical phenomenon called diffusion, which we will discuss later.

In addressing the properties of light, in air or in any other transparent medium, we must recognize that there is some loss or attenuation of light energy. This loss is largely due to absorption and/or scattering as the lightwaves propagate through the medium.

Energy Levels of Light

The energy level of a single photon of light depends upon its frequency. For example, a photon of red light would have an energy level of only 2 or 3 electron volts (eV). An ultraviolet photon might have an energy level of 300 eV, and an X-ray photon perhaps as much as 40,000 eV.

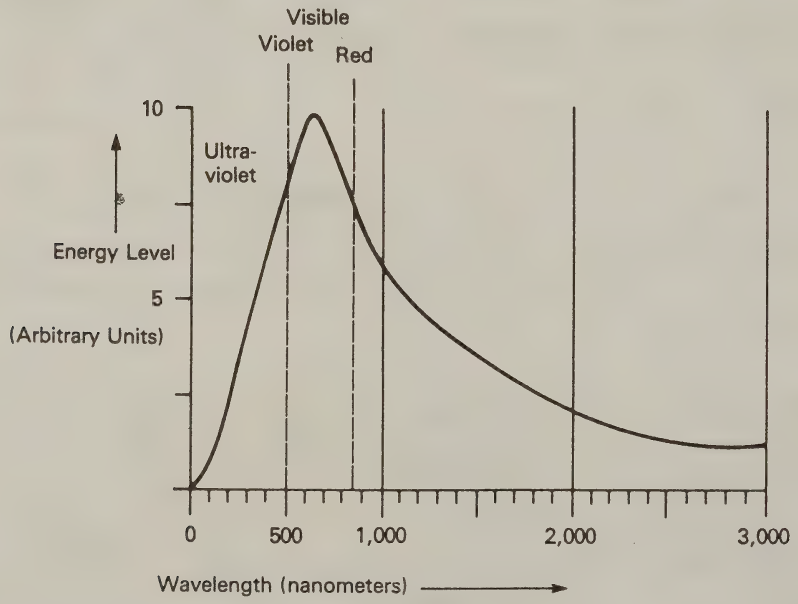


Figure 23-10 Planck Curve

The energy level of a single photon is quite small, but a great many photons may be emitted from a light source in a short period of time. An ordinary flashlight, for example, might emit a quintillion photons or more in a second. A quintillion is 10^{18} while a billion is only 10^9, so that a quintillion is 10^9 billion.

Although the energy level of a photon is constant, and dependent on frequency, if the intensity of the light is increased, the number of photons emitted will increase. Consequently, the thermal energy imparted to the atoms and molecules of a body that the light strikes will increase, and can become quite substantial. On a bright sunny day on a beach, the sand can become too hot to walk on due to this thermal energy.

Groups of atoms such as the sun give off radiation at all frequencies. It is possible to plot the energy distribution in a Planck curve (named for the German scientist Max Planck) as shown in Figure 23-10.

As a point of interest, the typical response of the human eye to visible spectrum lightwaves is shown in Figure 23-11.

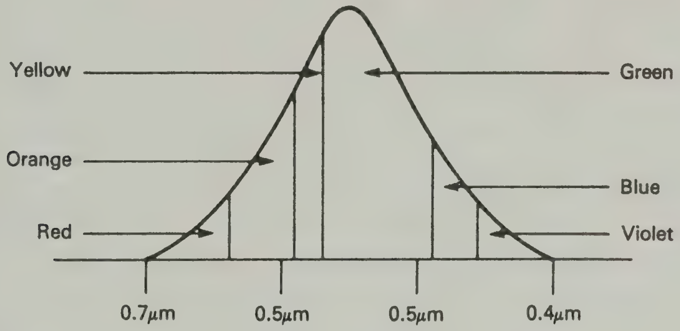


Figure 23-11 Response of the Human Eye

Summary

Light cannot be thought of as a system of waves alone or as a system of particles. Sometimes it acts as waves and sometimes as particles, but neither explanation can be considered as complete in itself.

Light is kinetic energy, that is, energy associated with motion. The unit of light energy is the photon. Photons exist as such only when they are moving, and when the light is absorbed by a material or substance, the photons cease to exist. The energy of the photons is converted to some other form of energy, as heat for example.

Since light is electromagnetic energy that travels in a wavefront, like sound or radio waves, light can be identified within the general electromagnetic spectrum.

At lightwave frequencies, it is more convenient to use wavelength rather than frequency. At such frequencies, the wavelengths are very short and are usually denoted in nanometers (nm), a unit of length denoting one billionth (10^{-9}) of a meter.

The spectrum generally referred to as light in laser or telecommunications fields extends from the near ultraviolet region (approximately 300 nanometers) through the visible light range (approximately 400 to 750 nanometers) and into the mid-infrared region (approximately 3,000 nanometers).

We can address light as a form of energy in applications that utilize light as a medium for transferring energy, such as in telecommunications systems.

With a basic understanding of light, we can usefully discuss those properties and mechanisms that may be particularly significant in general, and generating, modulating, propagating, and detecting light in particular.

Chapter 24

Light as a Transmission Carrier

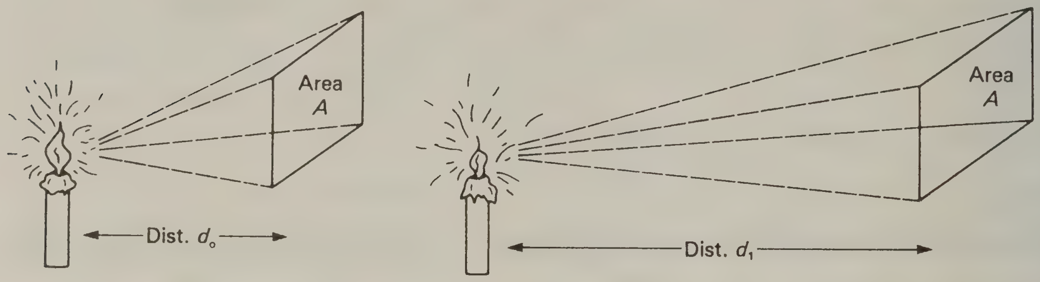
Light is mostly familiar to us as an illuminating agent, and from this perspective we are little concerned with the energy content of the light rays other than how it affects the intensity of the illumination. We are interested in how the energy is absorbed by material or substances upon which it may impinge, since that will determine the color sensation we receive. When we attempt to utilize light as a transmission carrier however, we are obliged to consider the light energy as a level of power, in the same sense that we do with electrical energy in copper conductors for example, or microwave transmission systems. In lightwave transmission systems, the amount of power that will be available at the end of long interconnecting optical fibers is a very real and significant factor.

In any of these cases, we must calculate the transmission losses of the system in order to predict the power level that will be presented to the system receiver or detector. Toward these ends, it behooves us to consider, in greater detail, the illumination related features of light.

Light as Illumination

Lightwave energy can be detected at points distant from the light source after propagation. The human eye is a natural detector of lightwave energy, but devices can be fabricated to detect light also. Applying the photoelectric effect, light meters can be manufactured that measure the electrical energy created by light particles falling on a photoelectric material.

The Law of Inverse Squares applies in illumination just as it does in other disciplines. The illumination of a surface by a point source of light varies directly with the intensity of the light source, and inversely with the square of the distance from that source. As shown in Figure 24-1, if a sheet of paper is first held two feet away from a light source, and the illumination is measured, and then the paper is moved to a spot only one foot away from the source, the measured illumination would now be four times greater than the original measurement. The Figure shows several examples of the application of the Law of Inverse Squares.



If x_o = illumination of A at d_o then $\left(\frac{d_o}{d_1}\right)^2$ x_o is illumination level at d_1

Example: $x_o = 1$ unit of illumination if $d_o = 1$ foot

If $d_1 = 2$ feet, then $\left(\frac{d_o}{d_1}\right)^2 x_o = \left(\frac{1}{2}\right)^2 \text{x}1 = \frac{1}{4}$ unit

If $d_1 = 3$ feet, then $\left(\frac{d_o}{d_1}\right)^2 = x_o = \left(\frac{1}{3}\right)^2 \text{x}1 = \frac{1}{9}$ unit

Figure 24-1 Law of Inverse Squares

Since we are dealing with electromagnetic waves, we can fabricate and apply a variety of devices to focus, concentrate, or narrowly direct the light from the source, rather than simply radiate it in all directions. The effect will be narrow beams of light that will be higher in intensity, and thus may propagate farther, or may be more easily detected at a distant point.

Although the terms candle, foot candle, and illumination may suggest light energy wavelengths within the visible spectrum only, other non-visible wavelengths can be processed by the same basic optical techniques. That is, all lightwaves can be focused, filtered, etc., just as visible lightwaves can.

In one sense, the fact that some wavelengths are visible simplifies the study of light, since we can actually perceive many of the phenomena we are discussing. In the study of electricity or radio wavelengths, this facility is not available to us.

Color is a function of the wavelength of light, and Figure 23-4 shows the relationship between various color wavelengths. The total absence of light energy within the visible spectrum, which is also the total absence of any colors, is black. The presence of all wavelengths within the visible spectrum, which includes all colors of course, is white.

Light Related Terms

A number of terms are employed to talk directly about light as illumination. *Radiant* is "something that radiates, as a point or substance from which light emanates." *Incandescence* is "emission by a hot body of radiation that makes it visible."

Luminescence is "an emission of light that is not ascribable directly to incandescence, and therefore occurs at lower frequencies, and is produced by physiological processes such as chemical action, friction, or electrical action." *Fluorescence* is "emission of, or the property of emitting, electromagnetic radiation, usually as visible light resulting from, and occurring only during, the absorption of radiation from some other source." *Transparency* is "having the property of transmitting light without appreciable scattering, so that bodies lying beyond are entirely visible." *Translucent* is "permitting the passage of light, but transmitting and diffusing the light so that objects beyond cannot be seen clearly." *Opacity* is the quality or state of a body that makes it impervious to the rays of light."

Propagation of Light

How far can you "see" light? What mechanisms introduce attenuation to light energy in a vacuum, or in any other transmission medium?

Astronomers describe the size of our galaxy by using a measurement of distance known as *Light years*. A light year is the distance it would take a beam of light a whole year to travel. Since light travels at a speed of 186,300 miles per second in a vacuum (space), in a whole year at this speed light would travel about six trillion miles (6×10^{12}).

The human eye can detect light from the stars in this galaxy, so obviously, light can travel a very long distance indeed, at least in a vacuum. As a point of reference, the sun is about 93 million miles away from earth, and it takes about 8 minutes for light from the sun to reach earth. The star nearest to earth is 25 billion miles from earth, and its light, perceptible on earth, takes four and a quarter light years to travel this distance.

Since there is no atmosphere in space, there is no attenuation or decrease in light energy, and the light travels these immense distances with relative ease unless an opaque object, such as another celestial body, intervenes. When light enters the earth's atmosphere, or travels in other media such as water or glass, the situation changes drastically. The earth's atmosphere, composed of gasses, extends out from the earth's surface about 100 miles or so.

Imagine a theoretical transparent medium that has been carefully freed of all dust and other suspended particles. If a strong beam of light were passed through this medium, observations in a dark room would show that there is still a small amount of bluish color light scattered from the beam itself, and this light would be visible. This may be observed when a large searchlight is pointed at the sky on a clear night.

This light, which is about 450 nanometers in wavelength or the color blue, is being scattered by the molecules that make up the medium. No scattering can be attributed to dust or other suspended particles, since we supposed that they were completely absent in the theoretical medium.

This particle free, transparent medium is exactly what the earth's atmosphere is, at least most of it. There are suspended particles in the lower sections of the atmosphere, but not in the upper regions we are discussing here.

The classical example of such molecule light scattering is the normal color of the sky, which is blue. At one time, the blue color of the sky was believed to be due to the scattering of light by dust particles that were suspended in the air. It was Lord Rayleigh who first showed that the nitrogen and oxygen molecules in the air were actually responsible for it.

The Rayleigh theory demonstrates that whatever the transmission loss of an optical fiber may be, transmission losses in lightwave systems will always be lower at longer wavelengths. Figure 24-2 shows the relationship between scattering intensity and wavelength.

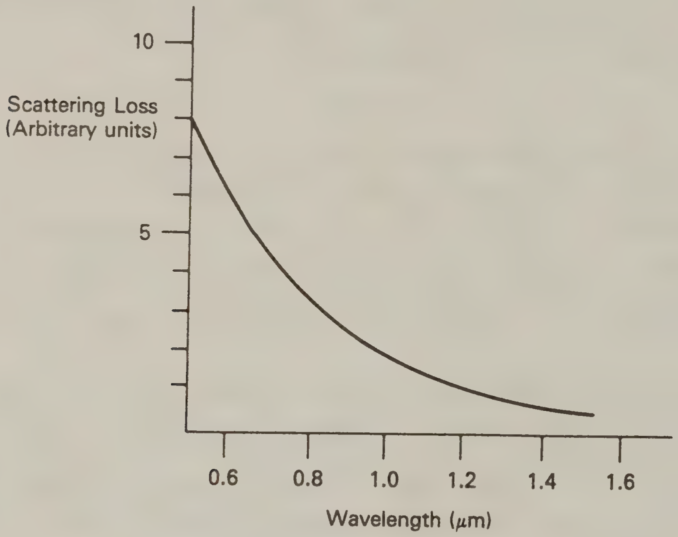


Figure 24-2 Rayleigh Scattering

Since the shorter wavelengths (blue is a short wavelength) are scattered more effectively than the longer wavelengths, a beam of sunlight (white light containing all visible light wavelengths) passing through the earth's atmosphere, will experience more depletion of blue light than it will yellow or red. Light energy at all wavelengths will penetrate the earth's atmosphere, but there will be less blue light than yellow or red at that point.

Light Absorption

Scattering should not be confused with reflection or diffusion. In Chapter 23 we learned that light can strike a substance and give up some, or all, of its energy to the molecules of that substance. If the atoms of those molecules of the substance had retained that energy, it is converted to heat, and the process is called *absorption*. If, on the other hand, the light energy given to the atoms of that substance raised their energy level to the point where they, in turn, emit light at the same wavelength as the incident or exciting light, the process is called *scattering*.

The emitted or scattered light is polarized in the process, as well as being radiated in all directions. Thus, the sky appears to be of a diffused blue color.

This same mechanism of molecular scattering is experienced in other transmission medium, such as glass or fluids. The nature of the substance and its molecular structure dictate the nature of the scattering that will be incurred. In a transmission medium such as glass, scattering is one form of depletion or attenuation of the light energy itself, of course.

Light scattering of a different kind is experienced in the lower regions of the earth's atmosphere, where suspended particles such as dust or moisture (fog, rain, etc.) are present. At sunrise or sunset, for example, the sun is low in the sky and to the viewer, the light travels through more lower atmosphere air than during the daylight hours. These suspended particles tend to scatter all colors of light except the red wavelengths, which travel directly to the eye, the detector, and the sun appears to be red.

With increased particle size, the scattering intensity becomes less dependent on wavelength until, for sufficiently large particles, there is no dependence on wavelength at all. Clouds, for example, might scatter other colors than blue if all particles were of a relatively uniform and large enough size. In fact, conditions have been observed where the sky appeared red and the sun appeared blue, but since clouds generally have a wide particle size distribution, they scatter all wavelengths of light equally well. Thus clouds usually reflect white light and appear to be white or gray, and only rarely colored.

With very large particles, the result is more properly described as *diffraction* rather than true scattering.

The primary causes of attenuation of light in air or in other media are absorption and scattering, and both mechanisms will be encountered when we examine lightwave transmission through optical fibers. The term *extinction* is sometimes encountered and may be erroneously used synonymously with the term "absorption." Extinction of light is the reduction of light energy to a level where it can no longer be detected. Extinction is a broader term than absorption, and indeed, it may include attenuation by both absorption and scattering.

Measuring Light

The process of measuring electromagnetic energy, regardless of whether or not we can see such energy, is called *radiometry*. *Photometry* is restricted to measuring that portion of the electromagnetic spectrum that is perceivable to the human eye as the sensation of light.

There is a curious relationship between radiometry and photometry. The fact that electromagnetic energy occurs in the visible region of the spectrum does not define the visual effectiveness of that energy. A blue lamp, for example, may emit the same radiation power in watts in the visible range as a green lamp, but the green lamp would appear to be brighter because the human eye is more sensitive to the green light than it is to blue.

Radiometric terms apply anywhere in the electromagnetic spectrum, whereas photometric terms apply only in the visible region of the spectrum. Outside of the visible range, there can be no light, by definition. Consequently the terms, units, and quantities of photometry do not apply.

Radiant Energy as Power

Radiant energy is energy traveling in the form of electromagnetic waves. Radiant energy density is the energy per unit volume, and the radiant power, also called radiant flux, is the radiant energy transfer per unit of time.

Radiant energy is measured in the same units of power in general. Since power = work/time, and work = potential energy = force X distance, the unit of power is:

$$1 \text{ watt} = \frac{1 \text{ newton-meter}}{1 \text{ second}} = \frac{1 \text{ joule}}{1 \text{ second}}$$

Power is the central term of radiometry, and its unit is the watt. Instruments for measuring radiant energy are called radiometers, and the equivalent units for measuring visible light are called photometers. Many kinds of devices are made to measure radiant energy. Some utilize photosensitive material and measure the electron flow that results from the light photons striking the material. In effect, these devices count the number of impinging photons and are calibrated to read directly in power units, usually some fraction of a watt.

Light as a Transmission Carrier

We know that light can be generated. We know that light will propagate through a vacuum, through air, and through other media as well. We know that light can be detected. These properties of light provide the essential components of lightwave transmission systems that follow the traditional configuration of other transmission systems.

But transmission systems require a modulated source of energy (a transmitter), a transmission medium through which the energy can propagate (copper conductors, air, glass, water, etc.), and a detector to sense the energy at the distant terminal and recover the intelligence which was modulated on to the carrier (a receiver). If light generators, i.e. sources of light, can be modulated with intelligence in some manner, all the necessary functions of a transmission system can be performed.

Modulation

Modulation is the process whereby the amplitude, frequency, phase or intensity of a carrier of signal is varied in accordance with these same properties of some other signal, which is the intelligence to be transmitted. In its simplest form, modulation involves simply turning a carrier “on” or “off.”

The intelligence could be encoded by a variety of intervals during which the carrier is on or off, as in Morse code radio transmission. This technique, using light as the carrier, is the "blinker" semaphore used to communicate between ships, for example.

In radio or microwave transmission systems, there are a variety of modulation techniques in general use, such as frequency or phase modulation and amplitude modulation. These are generally analog in nature, that is, the intelligence signal is continuously varying and is not expressed by discrete states of amplitude, phase, or frequency. Some examples of analog signals are audio signals on telephone Exchange lines, video and audio signals broadcast to television receivers, etc.

Another form of modulation is digital, where a signal is expressed in discrete states, that is, the absence or presence of a voltage, the level of amplitude of a voltage, or the duration of the presence of a voltage. Information to be transported may be assigned value or meaning by combinations of the discrete states of the signal using a code of pulses or digits. Some examples of digital signals are data in the form of pulse streams, and voice channels digitally modulated for telephone trunking applications.

Both analog and digital signals may be multiplexed, that is, may be combined or jointly carried with other signals on a transmission facility. In the case of analog signals, they may be separated within the transmission system by frequency division multiplexing or separating each signal on a carrier of a different frequency. This is the usual method of carrying a number of analog television signals on a conventional Cable Television system, where individual signals are retrieved by tuning its particular carrier frequency.

In digital multiplexing, several digital pulse streams, each constituting a different signal, are interlaced in time as pulses in a more massive, single pulse stream at a higher transmission bit rate.

Digital multiplexing of many circuits into a single transmitted pulse stream is a common, well established technique in telephone trunk transmission where, at both terminals, all circuits terminate or originate in Central Offices, thus greatly simplifying timing. Digital multiplexing is not in common usage within the Cable Television industry. One reason is that the end device the cable television system must serve is an analog type television receiver which is subscriber owned.

If digital modulation were used, indeed if digital multiplexing were employed, some digital to analog conversion would be necessary to feed these existing analog subscriber sets.

If the transmission system is broadband in nature, individual carriers on that system may be digitally or analog modulated of course, and may be carried together, if some sophistication in terminal devices and treatment is acceptable. Since each signal is separated in frequency, and thus can be recovered individually, there is no common modulation scheme imposed by the transportation system itself.

Lightwave Transmission Systems

In developing practical transmission systems for telecommunications purposes, we are constrained by all the conventional obligations, that is, we are obliged to design, construct, and operate over long periods of time, transmission systems that maintain relatively constant and acceptable transmission quality at all points within the system.

In order to do this, it is necessary to use standard units of measurement, to be thoroughly familiar with such units, and to be comfortable with their usage as well. The two basic considerations in any transmission system are the signal level (the amplitude of the carrier itself) and variations in the signal level, which may be translated to transmission loss or gain as the signal traverses the system. As mentioned earlier, power is the basic quantity used in radiometry and its unit is the watt.

It is possible to do all system engineering and even system maintenance work using actual signal power levels, but this is somewhat awkward. For example, it is sometimes difficult to refer transmission losses as changes in power levels. Moreover, if the basic unit of power is the watt, we would find it necessary to make many calculations with small units. This would not only be tedious, it could introduce errors in calculation.

A more conventional method has evolved over the years in other disciplines. We can use units of measure that are equally compatible with signal levels or transmission losses and gains. Then the development of precise signal levels at any point within a system, at any time, would be a simple matter of addition or subtraction. The concept is to deal not with the absolute power levels, but with ratios of power. Readers will certainly be familiar with this technique from earlier chapters of the book.

In lightwave transmission systems we use the familiar term *decibel*s (dB) to express ratios of power for purposes of denoting system transmission loss or gain. A negative value of dB denotes loss, a positive value gain.

We use dBm (decibel-milliwatt) as a convenient unit of power for purposes of denoting system transmission levels. The value given to zero decibel-milliwatts (0 dBm) is a power level of one milliwatt, which may be correctly written as 0 dBm, 0.001 watts, or 10^{-3} watts. A negative value of dBm would indicate a power level below 1 mW, and a positive value, a level above 1 mW. For example, -3 dBm would denote a precise power level of 0.5 mW, since -3 dB would be a one to two ratio, or one half. A value of + 3 dBm denotes a power level of 2 mW (a power ratio of 2 to 1).

Summary

Light may be considered as an illuminating agent, or as power. Different terms are involved depending on how light is addressed, and even the terms or measurements are not the same.

The Law of Inverse Squares applies to light as an illuminating agent, just as it applies in other disciplines. Because we are dealing with electromagnetic waves, we can focus, direct, and concentrate light energy through the use of various optical devices.

Some wavelengths of light are visible to the human eye but many of the wavelengths that we utilize in practical lightwave transmission systems are not. These non-visible wavelengths may be treated or processed using conventional optical mechanisms.

When light passes through a medium that includes gases or other particulate matter, it may be absorbed or scattered by the molecular nature of the medium it is passing through. If the atoms of the medium retain the light energy, the phenomenon is called absorption. If the light energy raises the energy level of the atoms to the point where they, in turn, emit light at the same wavelength as the incident light energy, the phenomenon is called scattering. Scattered light is polarized and is radiated equally in all directions.

Both visible and non-visible light can be measured. Light energy may be measured as power in the same units used in other disciplines, and the unit of measure most frequently employed is the Watt.

As in other disciplines, transmission calculations in lightwave systems use ratios of power rather than absolute power levels.

Chapter 25

Introduction to Optical Fibers

Lightwave energy can be launched into, and will propagate through, optical transmission lines. Such transmission lines are known as *optical waveguides*, *lightguides, or optical fibers.*

The use of these transmission lines presents a spectrum for private use, that is, no transmissions or emissions are launched into the public spectrum, which is defined here as free space. Thus no licensing by any Government agency is required, and the system operator is entirely free to allocate transmission frequencies or services within the confines of this private spectrum in any manner he or she decides. In this respect, lightwave systems are similar to conventional RF broadband coaxial cable systems.

As in transmission lines in other disciplines such as metallic conductors or microwave waveguides, the nature of lightwave transmission lines is to confine the light rays within the boundaries of the transmission line itself. This restricts access to, or exit from, the transmission line to taps or terminal devices that are provided in the design of the facility.

Since basic optical principles apply to the design and function of such transmission lines, the term optical fiber is used, and a number of such fibers may be incorporated into the fabrication of optical cables.

It is possible to launch light energy into optical fibers and such energy will propagate through the fibers. As in any transmission system, the transmission losses, and various forms of distortion, may be introduced into the lightwave signals themselves.

Basic Optical Mechanisms

Figure 25-1 (a) shows a light source (a flashlight) positioned to illuminate the end of a section of pipe, which we will assume has a highly polished inside interior. Note that the light beam is widely diverging so that some of the light waves will not be coupled into the pipe at all. Under these conditions, less lightwave energy is available at the distant end of the pipe for detection.

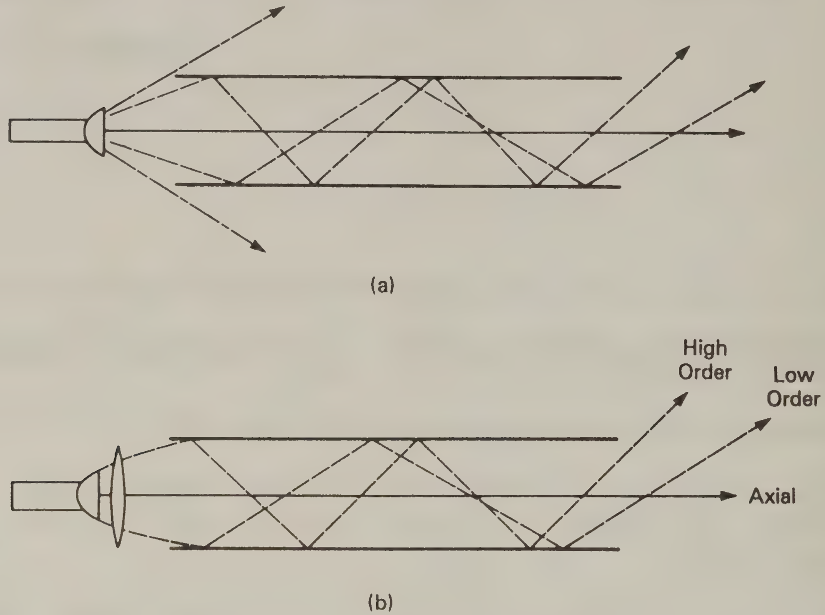


Figure 25-1 Reflective Propagation

In Figure 25-1 (b) a lens has been positioned between the light source and the pipe, which focuses the light beam more narrowly. Though the inner diameter of the pipe has not been changed, now more light is coupled into the pipe and thus more light energy will be available at the distant end.

Quite clearly, any light source that inherently emits a narrow beam of light will couple light into a light waveguide (the pipe) more efficiently. Some term to define the light-gathering capability of the light guide will be useful, and we might refer to this capability as *the degree of openness* or *the cone of acceptance* that the light guide (the pipe in this case) presented to the incident light from the source.

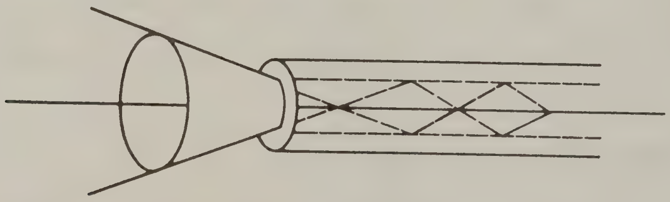


Figure 25-2 Cone of Acceptance

The term describing the "cone of acceptance" (shown in Figure 25-2) is called *numerical aperture*. Since the cone of acceptance establishes the angle of internal reflections within the pipe, it also determines the divergence of the light beam when it exits the far end of the pipe.

Propagation Modes

Figure 25-3 also demonstrates another optical phenomenon that will be encountered in lightguiding optical fibers. Whatever the divergence of the incident light beam may be, some light rays propagate directly along the longitudinal axis of the pipe. This propagation path is shown in both figures as a solid line, and the transmission path length along this line (the optical axis of the pipe) is the shortest possible distance through the pipe. This path represents one mode of light propagation within the pipe.

The figures also show some light rays entering the pipe at an angle (the dashed lines in the drawings). If the inner wall of the pipe were highly polished, these rays will be reflected from the inner surface and will propagate through the pipe in a series of reflective paths as shown. There may be hundreds of such reflective paths, and each such individual transmission path will be called a *propagation mode*, just as the axial transmission path was.

However many reflective propagation modes there may be, all will be longer in length than the axial mode, due to the multiple reflections involved. In Figure 25-1, reflective modes are designated as being higher order or lower order. This distinction designates the higher order modes as introducing the longest transmission paths through the pipe, of course. The axial mode is always the shortest and is sometimes referred to as the *fundamental mode*.

If all light rays travel at the same speed in a given medium, it follows that the reflective propagation modes will take longer to travel to the distant end of the pipe than the fundamental mode. Higher order modes require the longest transmission time of all.

Modal Dispersion

Consider a light source that is simply turned on and off a number of times. This procedure could be a form of modulation, with the intelligence contained in either the duration or the sequence of the on and off transmissions, or both. The on and off functions might be accomplished in response to an electrical input signal. If such a transmission were in actual use, the objective would be to faithfully reproduce the electrical signal at the distant end of the system.

If, at a given instant in time, the light source is turned on, all light rays at all lightwave frequencies will be emitted instantaneously. Suppose then that the light rays propagate through the pipe as in Figure 25-1. Then the light rays which arrive first at the distant end of the pipe will be those that travel in the fundamental mode, and thus travel the shortest path along the optical axis of the pipe. If the distant end of the pipe were coupled to a light detector, the detector would sense the presence of these rays and turn on its electrical output signal.

Then, at a later instant in time, the other light rays that were reflectively propagating through the pipe would arrive at the detector input and be sensed. But the detector electrical output would have already been turned on by the earlier arrival of the axially propagating waves, so no change would occur in the electrical output signal.

Now consider the sequence of events if the electrical input signal at the transmitting terminal of the pipe turned off the light source. In this case, all light rays at all lightwave frequencies would be extinguished at the same instant. The fastest reaction to this at the distant end would be the loss of light from the fundamental or axial transmission modes first, since this light travels the shortest distance. The detector would still be presented with some light input from the more slowly propagating reflective modes, so the detector output electrical signal would not be turned off immediately.

At some instant in time, after the slowest light rays (the highest order propagation mode) have finished traversing the pipe, the detector would no longer have any light energy input at all, would sense this condition, and turn off its electrical output signal.

The result would be an unfaithful reproduction of the original electrical input signal, since the electrical output signal would be of longer duration than the initial signal was. We say that the output pulse was *broadened* or *dispersed*, a condition shown in Figure 25-3.

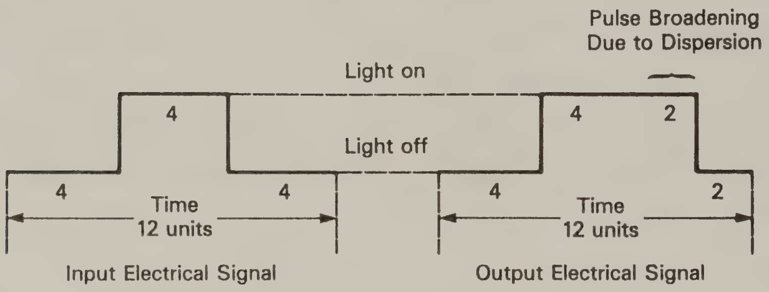


Figure 25-3 Pulse Dispersion

Broadening is a form of distortion of course, and is called *modal dispersion* in lightwave transmission systems. Clearly it is introduced by the multiplicity of transmission paths or modes supported within the pipe. How pronounced it will be is a function of the number of propagation modes that the pipe supports, and the length of the pipe also. This is called *multimode propagation* since a multiplicity of modes are present and sustained in the transmission medium.

Lightwave System Distortion

As in the cases of digital transmissions on metallic conductor and carrier systems, in lightwave systems we will also be somewhat constrained by the terminal device switching times (rise and decay times), but the mechanism for pulse distortion from the dispersion of light pulses is markedly different than in the other cases. As discussed earlier, pulse broadening in multimode graded index fibers is the direct result of the transit time differential between different modes of propagation, each with a different transmission path length. This modal dispersion may not be the only form of pulse distortion we have to contend with, but before we go on, let us be certain that we understand it's effect thoroughly.

In a digital lightwave system, if the light is turned on and off, a light pulse will be present for a digital ONE but no light pulse will be present for a digital ZERO. If no light is transmitted through the fiber during the off period (the digital zero), then there will be no modal dispersion of a light pulse during such a period, since no light rays and thus no modes of propagation are present.

During the light on period however, the light is transmitted, and the transmitted light pulse will be broadened as described earlier. In the electrical output signal of the receiver, the duration of the pulse and the no-pulse periods will not be the same as it was in the transmitter electrical input signal.

In effect, the output ONE pulse will intrude into the time period allocated for the output ZERO pulse. This is a somewhat unique and interesting difference inherent in lightwave transmission, and the term "pulse broadening" is particularly appropriate. Note that if we did not actually turn the light off entirely to indicate a no-input pulse condition, then the phenomenon would not have been evidenced.

The pulse broadening was the result of light transit time differentials, and had nothing at all to do with the intensity of the light. Thus, if we simply turn the light intensity higher and lower to denote the presence and absence of a pulse, the pulse broadening would be evidenced equally in both states of the output electrical pulse train. This technique of system operation might be called intensity digital modulation.

This interesting difference in lightwave transmission as compared with more conventional methods may be a bit academic, and even more so in analog lightwave systems. Unless the transmission bit rate were very high, the detection of the presence or absence of a pulse might not be significantly less dependable of course. But the text was to increase our understanding of lightwave transmission, and this mechanism is somewhat peculiar to that technology.

Waveguide Dispersion

Another law of physics comes into play at this point. Light energy of a specific wavelength will travel at a different speed through a different media, that is, through media with different refractive indexes.

Since, in a single mode fiber, some light is propagating through the cladding material, and since the cladding does have a different refractive index than the core, then even if a single wavelength signal were presented to the fiber, some dispersion would be incurred due to the transit time differentials of the two materials (the cladding and the core). This phenomena is known as *waveguide dispersion.*

Waveguide dispersion is wavelength dependent and may well be more pronounced at one wavelength than at another in a particular fiber structure. At some wavelengths the fiber may even exhibit zero dispersion. By manipulating the fiber geometry (that portion of the fiber that is propagating the light), it is possible to shift the point of minimal dispersion in a fiber to a different place within the lightwave spectrum, or to flatten the dispersion curve so that less dispersion is presented across a significant range of wavelengths.

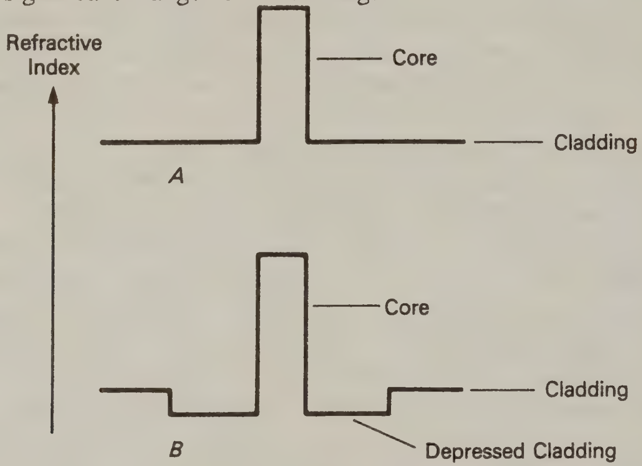


Figure 25-4 Dispersion Shifted Fiber

A fiber whose dispersion characteristics have been altered is called *dispersion shifted* or *dispersion flattened* and this is shown in Figure 25-4. Basically, all such changes would involve manipulation of the cladding material index within the physical confines of the mode field diameter.

Material Dispersion

A second form of distortion that involves yet another Law of Physics is evidenced in single mode fibers. At different wavelengths, light travels at different speeds, even in a constant and unchanging refractive index material. Thus even in a constant medium such as that presented by the fiber core material, and even if only a single mode of propagation exists, the speed of light will be different for different wavelengths of light.

Most light sources produce light output which contains energy at a number of wavelengths around the design "center" wavelength. Figure 25-5 shows the spectral output of a typical laser light source.

Although the output is centered at 1.3 um, it contains some lower level energy at wavelengths both above and below that value. The device is said to have a finite spectral width. Laser diodes have spectral widths on the order of 4 nm, while LED sources have a significantly greater spectral width of 40 to 100 nanometers.

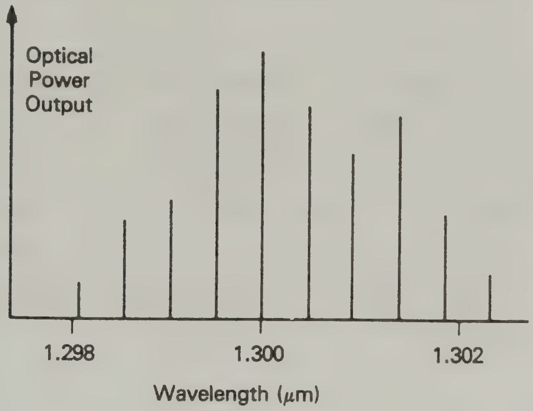


Figure 25-5 Spectral Width

Although the fiber supports only one mode of propagation, the energy launched into the fiber includes the several wavelengths shown in the figure. Despite the uniformity of the core material refractive index, these different wavelengths transit the fiber, and at different speeds. Thus a light pulse at the far end of the fiber would be dispersed in time, or broadened. This is called *material dispersion*.

Note also that lightwave sources are not perfectly stable. A source designed to output a light pulse with a wavelength of 1,300 nm will emit other wavelength pulses part of the time. As with waveguide dispersion, material dispersion will not be the same at all wavelengths, and it is possible to manipulate the refractive index of the cladding material to minimize the dispersion. It is also possible to select operating wavelengths that coincide with the minimum dispersion wavelength of a particular fiber.

Intersymbol Interference

Pulse distortion that is evidenced as a longer output pulse period than the input pulse period might be considered academic, since the input pulse has been extended by only a short period of time. This is truly the case at very low transmission speeds, such as when a ship uses blinker semaphore and Morse code. A slight extension of the light on period in relation to the light off period would be insignificant.

But in lightwave transmission systems, the light may be pulsed at significantly higher rates.

In a system operating at 90 Megabits per second (90 Mb/s) for example, the pulse period that the light is turned on is only six to ten nanoseconds or so, and 90 Mb/s is not a particularly fast or uncommonly encountered data rate in today's technology. The pulse distortion introduced can consequently be a significant percentage of the normal pulse period in such applications.

At higher transmission data rates, more bits (pulses) are transmitted per unit of time. The pulses tend to spread out, as discussed in modal dispersion, and an individual pulse will begin to intrude into a "no pulse present" time slot. This complicates the process of trying to determine, at given instants, whether a pulse is actually present or not. The intrusion of a pulse into an adjacent time period is called *intersymbol interference* and is shown in Figure 25-6. Such distortion can result in errors in data transmitted through a system or link, and in digital transmission (data or intelligence as pulses), can be serious.

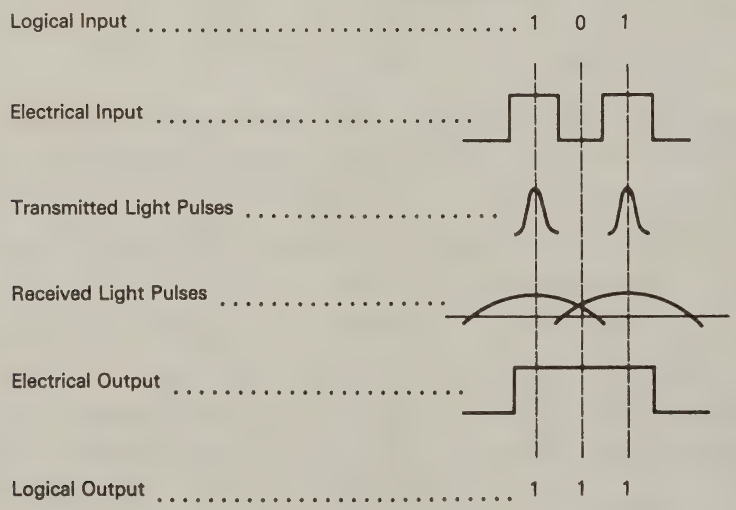

Logical Input 1 0 1
Electrical Input ....
Transmitted Light Pulses ....
Received Light Pulses ....
Electrical Output ....
Logical Output 1 1 1

Figure 25-6 Intersymbol Interference

Single Mode Propagation

In Figure 25-1, we saw the reflective mechanisms that the pipe provided, and the multiplicity of propagation modes that were sustained within the pipe. A significant reduction in modal dispersion (pulse distortion) can be achieved by simply reducing the inside diameter of the pipe, as shown in Figure 25-7.

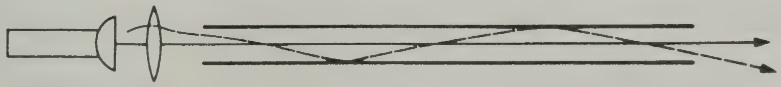


Figure 25-7 Reduced Inner Diameter

Although several reflective propagation modes are still supported, since the reflective transmission paths through the pipe are shorter, even for the higher order modes, the transmission times will be shorter also. It follows that the transit time difference between the fundamental (axial) mode and the worst case reflective modes (higher order modes) will be reduced. In effect, all rays propagated will travel nearly the same distance, and the modal dispersion or pulse duration distortion introduced will be less pronounced.

If it were possible to reduce the inside diameter of the pipe even further, perhaps to pinhole size or smaller, for example, this might restrict propagation to the axial node alone, which would effectively eliminate, or perhaps dramatically reduce, all pulse distortion. This condition is called *single mode propagation*, since only one mode (the axial mode) would be supported within the pipe, or very nearly so. Figure 25-8 shows single mode propagation.

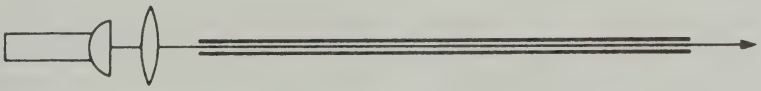


Figure 25-8 Single Mode Propagation

Note that with a very small inside diameter pipe, it is much more difficult to couple light into the pipe, and we must use a light source with a narrowly diverging light output and/or use some light focusing lenses, as shown in the drawing.

For information, Figure 25-9 shows another optical phenomenon, produced by a dent or mechanical irregularity in the pipe wall. Those light rays that previously propagated in an orderly and predictable manner now bounce off the irregularity in a random pattern of dispersal angles. Some may continue to propagate through the pipe, many new modes may be established, possibly introducing new and longer transmission delays with consequent modal dispersion. Some of these new rays may even be reflected back toward the entrance end of the pipe, reducing the level of light energy that will be delivered to the distant end for detection.

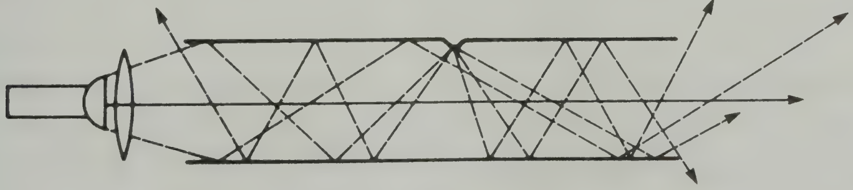


Figure 25-9 Mechanical Irregularities

Refractive Index

Thus far, we have used a pipe as a light guide, and assumed that the pipe was filled with air. But optical lightguides or fibers are solid glass and are not filled with air.

As light passes through a vacuum, its velocity is approximately 186,000 miles per second (300 million meters per second). Through air, the velocity of propagation is slightly slower, 299,739,000 meters per second. For practical purposes, we will assume the 300 million figure to apply in both instances.

When light passes from one medium to another, it changes speed. As discussed earlier, this introduces a deflection of the light rays called refraction. A term which defines this characteristic of media is *refractive index*. The refractive index of a medium is defined as the ratio of the velocity of lightwaves in a vacuum to the velocity of lightwave propagation in that medium.

The refractive index in a vacuum then, is 1.0. The refractive index of air is 1.003, often generalized to be 1.0 also. The refractive index of glass is 1.5. Put another way, when light travels in a denser medium, the speed of light (its velocity of propagation) decreases. This slower speed v, when divided into the speed of light in a vacuum c, yields the index of refraction n.

$$n = \frac{c}{v}$$

Some typical indexes of refraction are:

Medium	n
Vacuum	1.0
Air	1.003
Water	1.33
Fused Quartz	1.43
Glass	1.5
Diamond	2.0
Silicon	3.4
Gallium	3.6

Indexes of refraction are used in the design and fabrication of optical fibers.

Step Index Fiber

It is possible to fabricate optical fibers of silicon glass where the center mass of the fiber is glass material with a given refractive index, but the outer section of the fiber, which is also glass, has a different refractive index. This type of fiber is shown in Figure 25-10.

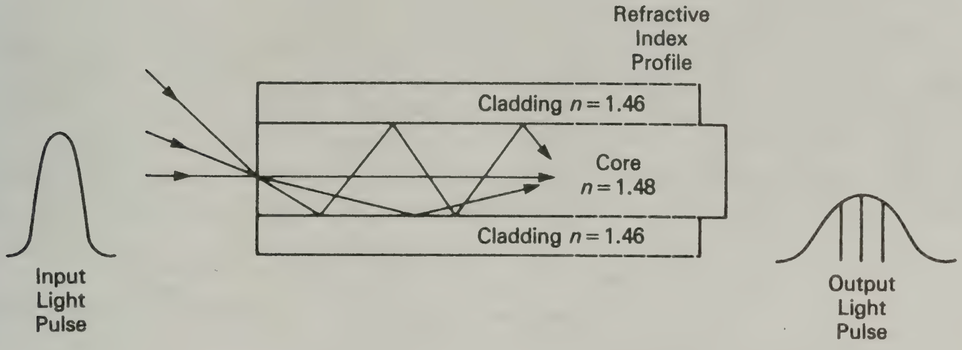


Figure 25-10 Step Index Fiber

Since the cross section of the fiber exhibits only one discrete change in refractive index, which is the line of demarcation between the two glass materials, this fiber is called a *step Index* fiber. The refractive indexes used in the figure are arbitrary and were selected for demonstration purposes only.

The outer layer of glass in a step index fiber has a uniform refractive index and is called the *cladding*. The center material has a different uniform refractive index and is called the *core*. It is possible to manipulate the refractive indexes of both the core and the cladding material by controlling the composition of those materials during fabrication. This is done by the judicious introduction of small quantities of other materials, a process called *doping*.

If the cladding material has a significantly lower refractive index than core material, it is theoretically possible to have total reflection by introducing light rays into the core that strike the cladding material at suitable incident angles. Then light propagation throughout the core will be constrained by the cladding material and reflected back into the core throughout the length of the fiber.

Given an optimum incident angle and an optimum difference in refractive indexes, the composite fiber will propagate light through the core in the same manner as the light propagated through the interior of the pipe in the earlier example. Within the fiber core, both axial and reflective modes will exist, and the mechanisms which introduce modal dispersion in the pipe example will be present in the fiber. The transmission distortion will be quite similar in both cases, fiber or pipe.

The ideal condition for efficient propagation within a fiber is not to have the reflective angles of propagation modes exceed the critical angle as they impinge on the cladding material. Light rays striking within the critical angle will be totally reflected back within the core, but rays striking outside the critical angle will be refracted into the glass cladding material. The mechanism to control the reflected angle within the fiber is to restrict the angle at which the light rays are launched or coupled into the fiber initially.

Numerical Aperture

The term used to define the angle of light entering the fiber is *numerical aperture.* It is a numerical figure that denotes the maximum angle of the light entering the fiber that will be propagated within the core material of the fiber. See Figure 25-11. All rays entering the fiber (refractive index, 1.48) from the air (refractive index, 1.0), are refracted toward the longitudinal axis of the fiber core, which is shown as the dashed line in the drawing.

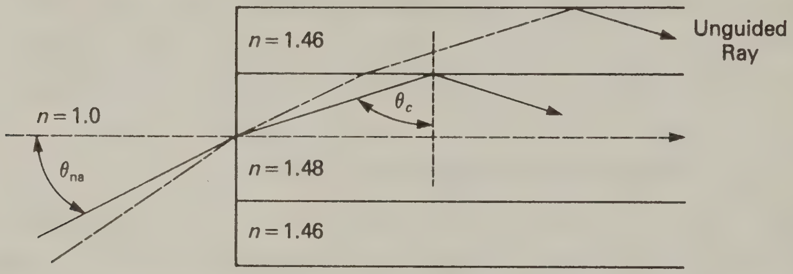


Figure 25-11 Numerical Aperture

The numerical aperture is a function of the core diameter and the indexes of refraction of both the core and the cladding material. In the interests of efficient propagation, that is, to ensure total internal reflection, it is desirable to design the fiber with the smallest numerical aperture possible. In multimode fibers, such a design essentially limits the practical dimensions of the core. If the core dimension were large, then the light could enter the fiber at angles that exceeded the critical angle at the cladding interface, and would perhaps create new high order propagation modes by reflection. These high order modes would allow light to be refracted into the cladding of course, and eventually this light would be lost for transmission purposes.

One might ask, *Why are optical fibers so small in diameter?* Certainly if fibers were two or three times their diameter they would still be sufficiently flexible for practical use, and certainly the additional glass material itself would not significantly increase fiber costs. If fibers were somewhat larger in diameter, they would have greater intrinsic mechanical strength, as well as perhaps being easier to splice together or apply fittings to. But the considerations given above restrict the core diameter, and this dictates the very small physical dimensions of practical optical fibers.

Of course the same optical principles apply to the distant or receiving end of the fiber as well. The numerical aperture will establish the angular dispersion of the light that is emitted from the end of the fiber. Just as the term *cone of acceptance* is appropriate in coupling light into a fiber, the term *cone of radiation* is appropriate for the emission of light from the fiber end.

Maximum fiber splicing efficiency, that is, the maximum transfer of light between two fiber ends, will depend to some extent on how similar the numerical apertures of the two fibers are. Also, the *cone of radiation* of light sources that must be coupled into optical fibers, and the *cone of acceptance* of light detectors that must accept the light output of fibers, must be considered.

In Figure 25-11 errant light rays, called *unguided rays*, are shown. These rays eventually enter the cladding material in this manner and are lost for transmission purposes.

Graded Index Fibers

So far, our discussion has been limited to step index fibers which support multiple propagation modes, and thus are called *multimode fibers*. The mechanism of light propagation in such fibers is directly analogous to the example of the pipe as a light guide. The analogy is useful in understanding modal dispersion, but the deficiencies of multimode (NOT single mode) step index fibers have virtually eliminated their use in telecommunications systems of any length.

The problem is that in a step index fiber, significant modal dispersion occurs because a multiplicity of propagation modes are supported by the fiber. The dispersion is the result of differences in transit time for the different modes, each of which has a different length transmission path. One technique for reducing modal dispersion is, as mentioned earlier, to reduce the fiber core diameter, and historically the ultimate outcome of this was a very small core which would support only one mode of propagation. This is called a *single mode* fiber.

There is another remedial measure however, that depends upon an entirely different optical principle. In our earlier example, which used a pipe as a light guide, the pipe was filled with air, which has a uniform index of refraction. Optical fibers can be fabricated so as to manipulate the refractive index in a variety of ways.

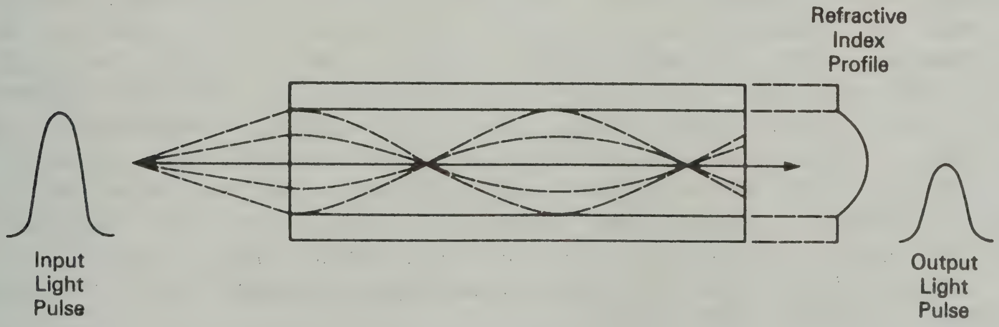


Figure 25-12 Graded Index Fiber

We can, for example, fabricate a fiber in such a manner that the refractive index of the core material is not constant throughout its cross section, but changes gradually. This can be done by fabricating the core with a series of concentric rings of material where each ring has a slightly different refractive index. We can vary the refractive index radially from the axis of the fiber to the outer limits of the core. Such a fiber, called a "graded index fiber," is also shown in Figure 25-12.

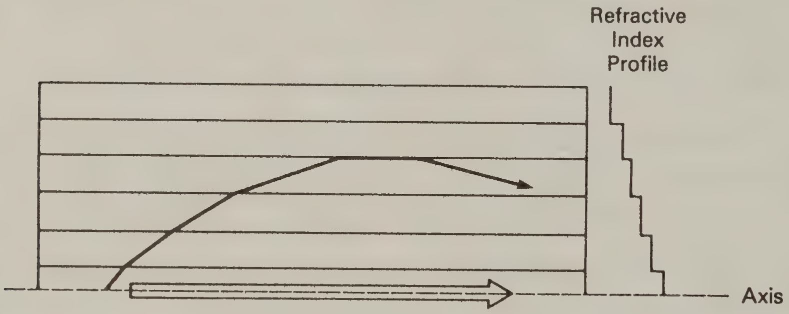


Figure 25-13 Graded Index Fiber

As light is introduced at an angle into a graded index fiber, the light rays pass through several different refractive indexes within the core material. Since light travels faster in the less refractive material that is located farther from the optical axis, not only is the light refracted back towards the axis, but the time differential between the axial propagation and the refractive propagation is greatly reduced. The refractive mechanism may be seen clearly in Figure 25-13, where the refractive index profile steps have been exaggerated to show the process.

In graded index multimode fiber, several propagation modes are sustained and different transmission path lengths exist, just as in the multimode step index fiber discussed earlier. The transit time over the longer transmission paths is reduced, however, due to the changing refractive index of the core material. Also, in graded index fiber, the cladding material has a distinctly lower refractive index than the lowest index in the core material. Thus a line of demarcation between core and cladding is maintained, and the cladding still acts to confine the light rays within the core material.

Graded index fibers require careful control of the processes whereby they are fabricated. Outside fiber diameters may be 125 um, and the graded index core diameter is 50 um or so in typical graded index fibers.

Figure 25-13 shows the effect of a varying refractive index on a ray of light in a graded index fiber.

Single Mode Fiber

A *single mode* fiber is basically a step index fiber since only one demarcation is established between the core and the cladding indexes. In a single mode fiber, the reduced core diameter restricts the propagation to a single transmission mode, just as reducing the inner diameter of the pipe did.

If the refractive index differential between the core and the cladding material is kept small, the fiber will behave as a true waveguide. It can be shown, using Maxwell's equations, that in a bounding waveguide, electromagnetic energy will propagate and be limited within the confines of the guiding structure.

In the case under consideration, the guiding structure is the optical fiber itself, and the light energy is bound within this structure. The light propagates longitudinally through the fiber, not by means of optical mechanisms such as reflection or refraction. A significant amount of the light energy, as much as 35 percent of the total lightwave signal, will actually propagate through the cladding material as shown in Figure 25-14.

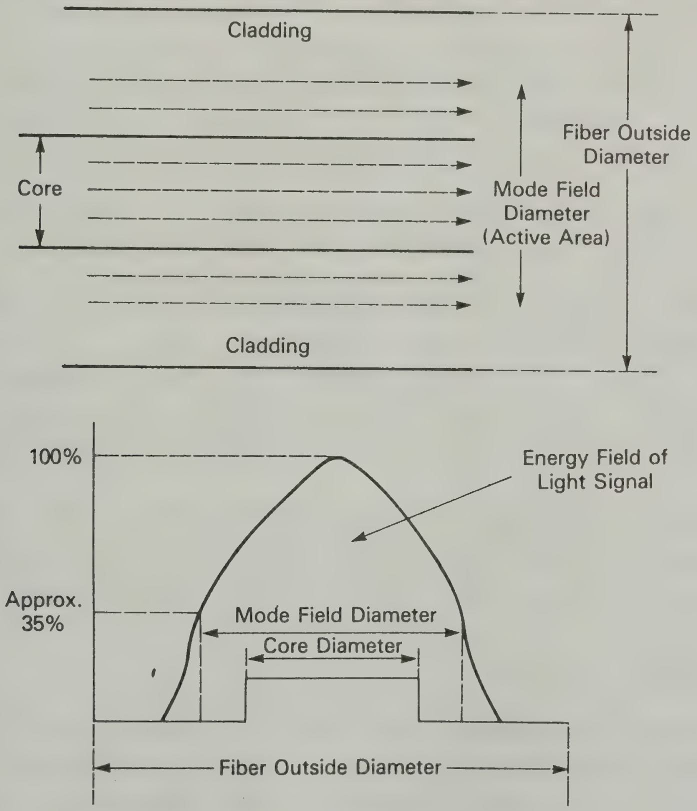

Cladding
Fiber Outside Diameter
Core
Mode Field Diameter (Active Area)
Cladding
100%
Energy Field of Light Signal
Approx. 35%
Mode Field Diameter
Core Diameter
Fiber Outside Diameter

Figure 25-14 Mode Field Diameter

Mode Field Diameter

When propagation is confined to the core area alone, the term numerical aperture (NA) is appropriate. Now, however, we must define a larger cross-section area of the fiber that includes some of the cladding area. This area, which is larger than the core but smaller than the outside diameter of the cladding material, is actually propagating light energy, and we might refer to it as the *active area* of the composite fiber structure.

Since some of the light propagation is effected through the cladding material, a new term, *mode field diameter*, (sometimes called spot size) is used to define the active or light-propagating cross section of the fiber, which includes all of the core and some of the cladding. Figure 25-14 shows the relationship of the mode field diameter to the fiber core diameter.

Mode field diameter increases with operating wavelength, and so at some specific wavelength, a single mode fiber will start to support more than one propagation mode and will function as a step index fiber. The frequency corresponding to this wavelength is called the *cutoff frequency* of the fiber and is the point in the spectrum below which more than one mode will be supported.

Cutoff frequency will be a function of fiber geometry and material, the refractive indexes differential, and the core diameter. Since all of these factors can be controlled during fiber fabrication, a fiber can be manufactured to have a specific cutoff frequency characteristic, if it is desired to do so.

If, to have a single mode fiber function as a waveguide, we desire the fiber for use at long wavelengths, we must manipulate both its core diameter and the refractive indexes during fiber fabrication. The core diameter will be slightly increased, and at some shorter wavelengths this large core size will propagate the light energy reflectively, just as it did in the large core step index fiber. The cutoff frequency is the frequency corresponding to the wavelength at which more than one mode will propagate through the fiber, and this wavelength will always be shorter than the design operating wavelength of the fiber.

The cutoff frequency may be of interest when more than one wavelength signal will be passing through the fiber, as in a *double window* fiber application or in a system applying wavelength division multiplexing. These applications are discussed later in this text.

Comparing Types of Fiber

Both graded index fibers (often referred to simply as multimode fibers) and single mode fibers reduce modal dispersion problems, but not to the same degree. In the next Chapter we will discuss fiber distortion, loss, and bandwidth characteristics in depth, but we can draw some interesting conclusions even now.

Although large core, step index fibers are not generally encountered in telecommunications systems of any appreciable length, they do find application in vehicles such as ships, aircraft, and the like, and in other applications where the transmission distances or the transmission data rate, or both, are nominal.

Large core, step index fibers have the following characteristics:

1. Their larger core greatly simplifies fiber connections and splicing.
2. Their large numerical aperture greatly simplifies coupling light energy into and out of them.
3. Both the modal dispersion and loss of light in cladding modes are sub stantial. Both of these penalties may be acceptable if the fiber lengths are limited or the data rates are low.

Multimode (graded index) fibers have the following characteristics:

1. Their large core somewhat simplifies fiber connection and splicing.
2. Their large numerical aperture somewhat simplifies coupling light into and out of them.
3. Their modal dispersion introduces some bandwidth restrictions, which limits transmission data rate to some degree. A typical usable bandwidth is on the order of 600 mHz per kilometer to perhaps 2,000 mHz per kilometer.

Single mode fibers have the following characteristics:

1. Their typical small core diameter complicates fiber connection and splicing.
2. Their small numerical aperture (spot size) complicates coupling light into and out of them.
3. Since they have little or no modal dispersion, they present a very wide bandwidth for use, and higher transmission data rates are possible, even with simple fiber structures.

Summary

Any source of light energy can couple light energy into an optical fiber. A source emitting a narrower beam of light will couple more light into a fiber than a source with a widely diverging beam. The term *numerical aperture* (NA) defines the acceptance cone of a fiber or a terminal optical device such as a photodetector.

Light may propagate directly, reflectively, or refractively through a fiber. If more than one mode of propagation is sustained, the fiber is called multimode. If only one mode is supported, the fiber is called single mode or monomodal.

There are differences in transit time through a fiber for different propagation modes. Thus some dispersion or pulse broadening is experienced in any fiber supporting more than one mode of propagation. This is called "modal dispersion."

In fiber that supports only one propagation mode, pulse dispersion may actually occur, but this mechanism is due to the difference in transit time between two or more lightwave frequencies being propagated, if more than one frequency is presented to the fiber. This is called "chromatic dispersion."

The cross section area of a fiber may exhibit several changes in refractive index of both the core and the cladding materials. If these changes are distinct transitions, the fiber has a step index structure. If the changes in refractive index are gradual, the fiber has a graded index structure.

In a graded index multimode fiber, all light energy propagates through the fiber core. In a single mode step index fiber, a significant amount of light energy actually propagates through the fiber cladding material.

Chapter 26

Light Transmission in Optical Fibers

Unwelcome things like distortion and attenuation happen to any signal passed through any transmission system, and lightwave systems using optical fibers are no exception. We must understand these mechanisms so that we can design systems that provide a usable transmission quality even after the inevitable degradation has occurred. In this case, we need to learn about what happens to light signals when they are passed through optical fibers. This will help us select fibers that introduce less degradation, or design more economical systems that perform well enough that we can accept the degradation and still use the system.

Just as electromagnetic waves can be injected or launched into transmission lines such as copper wires, so can lightwaves be launched into light guides or optical fibers. Transmission of light through optical fibers is, in some ways, analogous to electrical transmission through wires, but there are significant differences in the two technologies, and the principles of physics are quite different for each case.

Where electrons are caused to flow through a copper conductor, light is guided through an optical fiber. The optical propagation is much more analogous with microwave or radio waveguides. In waveguides, the energy does not flow through the material that constitutes the waveguide structure as through an electrically conducting material, but rather it is propagated as a wave through the space enclosed by the conductive waveguide walls.

Defining the Text Objectives

In a text such as this, one dilemma is deciding how deeply one should go into technical details of hardware, etc. In practical application, the reader is not designing light sources or lasers at all, but is incorporating such devices into a satisfactory transmission system, and cares little for the internal mechanisms of any device, only its overall performance and practical suitability.

And of course, since research into new variations or devices is ongoing, particularly in a relatively new development such as lightwave transmissions present, text material may be quickly outdated or superseded by new developments.

Nevertheless, it is our belief that students will be better prepared for any technology if they have some understanding of the basic principles involved. It is in that sense that we present this material. It is not necessary or essential that students be equipped to design and fabricate lasers for example, but they should understand their application and advantages or deficiencies.

Reviewing Lightwave Propagation

In lightwave transmission, the fiber functions as a *waveguide* for the light energy. The manner in which the light is confined within the two basic types of fibers (step index and graded index) involves distinctly different optical principles.

In a *step index, multimode fiber* the light is confined within the core material by total internal reflection, introduced by design at the core-cladding interface. In a *single mode, step index fiber*, the light propagates longitudinally through both the core and the cladding material. In the *graded index fiber*, the light is bound not by internal reflections at all, but by refraction due to the radially varying refractive index of the core material itself.

The two major considerations in addressing the transmission of lightwave energy through an optical fiber are transmission loss and signal distortion. These are, of course, the considerations of any transmission system.

If the signal being transported is analog in nature, then the noise and distortion will be quite similar to that incurred in other analog transmission systems, such as the broadband RF transmission covered in the preceding Chapters of this text. It will be largely related to the optical terminal devices, but some of the transmission effects within the optical fibers themselves will have an impact on the overall system bandwidth that is presented for use.

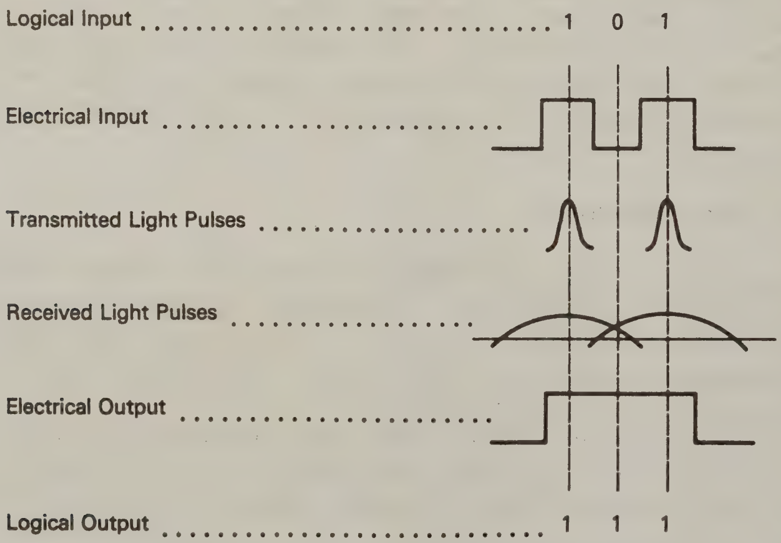


Figure 26-1 Intersymbol Interference

If, however, the signals being transported are digital in nature, the interference will be significantly affected as *pulse distortion* or *dispersion*, more familiar perhaps as pulse broadening. The effect of pulse dispersion is shown in Figure 26-1. Note that this effect is not particularly significant in an analog system, where the intensity of the light pulse may vary, but no rapid transitions of light intensity occur. The problem shown in the figure (exaggerated for clarity) is called *intersymbol interference* and at higher data rates can render a system unusable. This is because at higher data rates the pulse period is much shorter, and the dispersion becomes relatively larger in relation to the pulse period itself. Obviously such a problem must be addressed and solved.

Light Scattering in Fibers

The loss of light energy that occurs as light travels through a fiber can be attributed to several causes. The most pervasive factor, and perhaps the most significant, is *light scattering* within the fiber itself. The root cause of light scattering was discussed earlier, and the phenomenon, as it occurs in the fiber itself, is identical.

The molecules of the glass themselves absorb photons and re-emit light energy. These emissions are random, and the light so emitted does not propagate in a formal or predictable manner throughout the fiber. The net effect is a loss of light energy within the fiber, and a lower level of light energy is available for detection at the distant end of the fiber.

The Rayleigh scattering curves for a fiber, presented as Figure 26-2, depends upon the matter with which the fiber is fabricated. This does not mean that lower loss fibers cannot be fabricated. If the molecular structure of the silicon glass of the fiber itself is changed, then the light scattering losses of the fiber will be changed also.

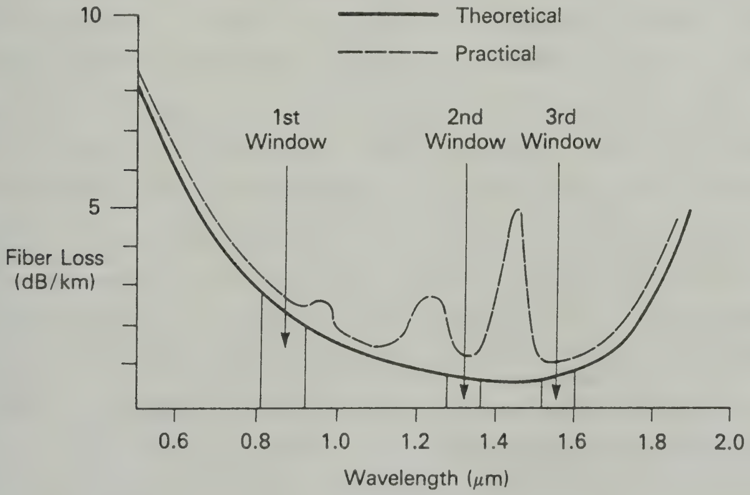


Figure 26-2 Fiber Attenuation

We can fabricate lower loss fibers by carefully adding different materials in a process called *doping*. But scattering loss is a function of wavelength also, and the Rayleigh curve will still apply, even to lower loss fibers. We will always experience lower fiber attenuation at longer wavelengths due to the scattering phenomenon.

If fiber composition is altered, the fiber design must be careful to alter both the cladding and the core material of course, since the relationship of the refractive indexes of these two materials is critical to the propagation of light within the fiber structure. Losses in fiber manufactured today come close to achieving the theoretical losses of the Rayleigh theory, but variations in fiber density during fabrication do introduce some variations in scattering loss throughout a long length of fiber, and actual losses are higher than those that are theoretically attainable.

Light Absorption in Fibers

Impurities in the fabricated glass itself, from which the optical fibers are drawn, introduce absorption of lightwave energy within the fibers. *Light absorption* has been discussed earlier, and is the condition when photons striking a substance give up some of their energy to the atoms of that substance, but those atoms do not re-emit the energy. The phenomenon of light absorption in fibers is the same as the general one, and the light energy is lost for transmission purposes. Absorption is one form of transmission attenuation in lightwave transmission systems.

Figure 26-2 shows the effects of both scattering and absorption as loss mechanisms in optical fibers. The high attenuation peaks shown at some frequencies are the result of foreign elements or impurities in the glass. Both ferrous and ferric (iron) ions absorb light in the visible range, for example. Another common impurity in commercial fibers is water, in the form of hydroxide ions, which introduce the highest loss peaks shown in the figure.

The figure shows an early generation multimode fiber, but present day production should not exhibit the pronounced attenuation peaks seen here, since much progress has been made in understanding these phenomenon and in producing fibers with lower levels of contamination.

Because the attenuation peaks due to impurities were so pronounced in earlier fibers, transmission designs focused on using frequencies where absorption was less oppressive. The terms *first window* and *second window* came into general usage, referring to those sections of the curve (see Figure 26-2) where fiber losses are minimal. The figure identifies the "windows," but as fiber quality improved, the terms became somewhat less significant and such references are now less frequent.

Fiber Attenuation Mechanisms

Another form of scattering loss results from variations in the size of the fiber core, irregularities in the interface between the core and cladding material, and *micro-bends* which sometimes occur during the process of cabling fibers or placing optical fiber cables. Fibers may be stretched over small imperfections in the cabling material itself during the cabling process. Figure 26-3 shows the effects of some of these conditions, all of which can be due to the limitations of the fabrication or manufacturing processes themselves.

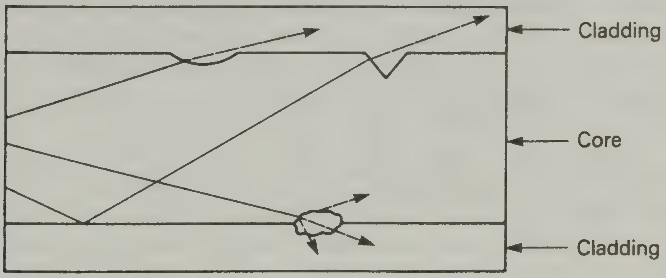


Figure 26-3 Micro-bends and Attenuation

As a fiber, or a cable made up of fibers, is handled in transportation or placement, other attenuation mechanisms may be introduced of course. As systems are constructed, optical devices such as fiber connectors or splices may be inserted into the fiber for various purposes. In so doing, the optical fibers may be subjected to sharp bends or excessive tensions. Any or all of these may attenuate light energy passing through the fiber, of course. Such attenuation, however, is *extrinsic* to the fiber structure, and must be addressed in the construction or the design of specific applications or systems.

Loss, or attenuation, may be described as a reduction in the energy level of a transmitted lightwave signal during its passage through the fiber, and it is usually expressed as a power loss ratio in terms of decibels per kilometer (dB/km). Obviously the stated loss in these terms will refer to a specific wavelength of light. The calculation of loss for a given length of fiber or cable is a simple mathematical process. A fiber specified to introduce 1.5 dB of loss per kilometer of length, would evidence 7.5 dB of loss end to end in a 5 kilometer length (5 X 1.5 = 7.5).

When we address system transmission designs, we will find some systems will be attenuation limited, that is, the transmission losses will reduce the signal power level below a reliably detected level and remedial measures will have to be taken.

Such measures might be to select a fiber with lower transmission loss, to select a receiver/detector with a lower threshold of detection, to select a light source or transmitter with a higher power output, or to select an operating wavelength where the fiber has evidenced less loss. An attenuation limited application may require the installation of an intermediate repeater of some kind.

Optical Transmission Levels

Since we are obliged to select both lightwave transmitters and receivers for use in specific applications, we must be able to establish and specify the optical transmission signal levels these devices must generate or operate satisfactorily with. A lightwave transmitter outputs lightwave energy into an interconnecting optical fiber. The transmitter output signal levels are usually specified in terms of dBm where decibels are referenced to 1 milliwatt. (0 dBm = 1 mW).

Referencing transmission levels rather than expressing them as absolute levels of power in either Watts or milliwatts, greatly facilitates system calculations, since transmission losses are specified in dB. Thus all calculations of signal level can be accomplished by simple addition or subtraction. This technique is the same as that used throughout this text in progressively calculating signal levels in conventional coaxial cable systems, and certainly should be quite familiar to us by now.

Transmitting losses are specified as negative decibels (-dB) of course, but lightwave transmitter output levels may also be specified as a negative value of dBm. This would indicate a transmitter whose lightwave energy output was some level below the 1 milliwatt reference power level. Some manufacturers may specify transmitter output as so many milliwatts of power of course, and this may be awkward or confusing in calculating system levels, but the conversion of one term to another is straightforward. Given power in milliwatts, the equivalent in dBm is given by the formula:

$$Pwr\ (dBm) = 10 \log Pwr\ (mW)$$

Table 26-1 gives some representative signal levels in milliwatts that might be encountered in lightwave systems, along with their equivalent values in dBm. Readers less familiar with decibels or decibel-milliwatts may find a review of Chapter 2 in this text helpful.

Milliwatts	*dBm*
10.00	*+10*
3.98	*+ 6*
1.99	*+ 3*
1.00	*0*
0.50	*- 3*
0.25	*- 6*
0.10	*-10*
0.01	*-20*
0.001	*-30*
0.0001	*-40*

Given transmitter outputs in dBm, and interconnecting fiber or other optical device losses in dB, it is a simple matter to establish quite precisely the lightwave signal level which will be presented to the lightwave receiver input.

Noise and Distortion in Lightwave Systems

Because lightwave systems can be designed and operated for digital or analog transmission, the terms used for noise and distortion are sometimes confusing or misunderstood. Some forms of distortion are unique to digital transmission systems, and the terms used in such cases reflect this. This text, however, is focused on the use of lightwave links in broadband applications using Frequency Division multiplexing, just as conventional coaxial cable systems are employed, and digital terms are not applicable or appropriate.

If, in the case of broadband analog applications, we use terminology similar to those used in coaxial broadband RF systems, then combining both technologies (fiber and coaxial cable) in a single transmission system can be readily accomplished. We have, earlier in this text, clearly shown how composite system performance can be developed by combining the transmission performance of individual system elements such as the Head End and cable plant, or trunk cable and feeder cable plant.

Many of the mechanisms in lightwave transmission may have effects or repercussions on other forms of system performance, and in many cases direct correlations can be made. An example might be the definition of digital lightwave transmitters and receivers in technical terms of *rise time*. The overall digital transmission quality may be established by due consideration of both rise times of course, but such definition is not directly applicable to analog transmission applications.

Fortunately suppliers of lightwave equipment for use in analog systems do use terms similar to those employed in coaxial cable plant, and we need not pursue the mathematical correlation of terms at all. For example, a lightwave transmitter will be specified to contribute *intermodulation distortion* products (second order beats, composite beats, etc.) when carrying a specified number of television signals at a stated optical output signal level. It is relatively easy, given similar terms, to establish the transmission performance end-to-end of a *hybrid system* that employs both optical fibers and lightwaves followed by a short section of coaxial RF broadband plant.

Nevertheless, it may expand our understanding of lightwave transmission to be somewhat familiar with those terms that are unique, or directly applicable, to digital transmissions on lightwave systems, even though we do not propose to operate such systems digitally at all.

Signal-To-Noise Ratio and Bit Error Rate (BER)

An optical fiber is immune to many of the noise influences that metallic conductors suffer from, such as electromagnetic coupling and transient signals. Wideband white noise can be introduced into lightwave systems through the transmitters and receivers however. Because the lightwave receiver is usually working with very low levels of input signals, it is the primary source of noise in lightwave systems. This is somewhat analogous to the front end or input stages of coaxial RF amplifiers, of course.

In speaking of lightwave systems, it is necessary to establish a term that relates system noise contributions to the transported intelligence itself. In coaxial cable systems you may recall the similar use of the term Carrier-To-Noise Ratio (C/N). In analog lightwave systems the term used is *signal-to-noise ratio* (SNR). This has the same meaning in any analog system, whatever the transmission medium may be. It is the difference between the amplitude of a signal (before modulation or after detection of a modulated carrier) and the noise present in that spectrum occupied by the signal, when both are measured at the same point in a system.

In digital systems we use the term *Bit-Error-Rate* (BER). This is defined as a ratio between the transmitted bits detected in error and the total number of bits transmitted. Thus a BER of 10^{-9} simply means that of a billion bits received, one bit was detected incorrectly. Quite obviously BER is directly applicable in digital transmission applications.

Note that where SNR relates primarily to the white noise contribution of the terminal equipment, the system BER is not a function of noise alone, but also reflects pulse distortion (dispersion). This distortion may be due to several causes in lightwave systems, including modal dispersion and chromatic dispersion (consisting of material and waveguide dispersion) of the lightwave energy pulses as they transit the optical fiber.

As a general rule, lightwave receivers are specified with input optical signal level referenced to the electrical output SNR in the case of analog signals, and BER in digital applications. For example, a manufacturer may specify that a specific receiver will produce a BER of 10^{-9} with a minimum optical input signal level of -40.5 dBm. If the optical input falls below this level, we expect that the output electrical signal quality may be poorer than 10^{-9} BER.

It is also possible to over-drive a receiver with too high an optical input signal level, resulting in some degradation of transmission quality. *Data rate*, sometimes referred to as *bit rate*, is the number of bits processed in a given period of time.

The BER we are prepared to accept for a system performance has an impact on bandwidth requirements. A narrower system bandwidth, may be equated to longer rise times within a system.

A general Correlation of BER and Signal-to-Noise Ratio

The BER of a digital system relates to the level of receiver input signal where the receiver fails to capture or lock up on sync pulses, and thus recovers no digital information at all, a condition sometimes referred to in digital transmission as *the system crashes*. We might relate measured BER to the measured C/N Ratio in a 4 mHz bandwidth. Typically, any digital system will exhibit some acceptable degradation of BER before dropping out, or becoming completely unusable.

For information only, and to relate these two terms somewhat, many years ago we generated a 70 mHz carrier and modulated this carrier digitally with four DS 1 signals multiplexed into a single pulse stream of 6.312 Mb/s. This presented 96 individual voice channels for use. We were able to measure the BER in a single digital voice channel of course, and to manipulate the transmission levels of the 70 mHz carrier as well. We applied this carrier to an existing coaxial system which included 18 RF amplfiers in cascade.

We gradually reduced the carrier level, which changed that single carriers C/N Ratio on a 4 mHz bandwidth basis. In this manner we were able to plot the C/N degradation with RF signal level changes, and the BER produced in a digital channel with RF signal level changes as well. The scientific merit of this field excercise may be in question, but as a general correlation of the two terms, it may be of interest to the reader.

For voice traffic (4 kHz channel) on a digital microwave system for example, BER of 10^{-6} is considered quite acceptable, producing one slightly audible click every 15 seconds or so. The circuit would still be quite intelligible, but quality drops off repidly below this point. For digital data service, a BER of 10^{-8} is generally accepted as a usable circuit.

TASO Picture Rating	S/N Ratio
1. Excellent (no perceptible snow)	45 dB
2. Fine (snow just perceptible)	35 dB
3. Passable (snow definitely perceptible but not objectionable)	29 dB
4. Marginal (snow somewhat objectionable)	25 dB

Figure 26-4 TASO Rating

For contrast, as figure 26-4, we show the TASO ratings, one series of tests frequently referenced in television and conducted by the Television Allocation Study Organization (TASO). The results were published in a report to the Federal Communications Commission (FCC) many years back.

We found that a BER of 10^{-8}, a very usable voice circuit for data service, roughly equates to a 4 mHz bandwidth C/N Ratio of 23db or so, far below the acceptable quality of any television signal. Television is a much more difficult and spohisticated task than transmission of high quality voice circuits.

Bandwidth and Rise Time

Rise time may be defined as the time period required for the instantaneous amplitude of a pulse to go from 10 to 90 percent of peak pulse amplitude. When the electrical interfaces with the lightwave link or system are electrical pulses (a digital application of course), it is common practice to use the term *rise time* to denote all pulse distortion as it is present in the electrical output pulse. We may also encounter the term *System Rise Time Budget*, which is used to help characterize the transmission performance of a link.

Since the terminal equipment consists of discrete units (transmitters and receivers) we can define and measure the electrical bandwidth of such units, and in analog applications, bandwidth is important. The *electrical bandwidth* is usually specified in Hertz, and is generally defined, in both equipment and systems, to be the spectrum provided for use to the half power points. This means that no signal, at any frequency within the bandwidth of the unit or system, will be attenuated greater than 3 dB more, than the signal within that bandwidth that is attenuated the least, or is the highest in amplitude. The signal least attenuated is usually at a frequency in the center of the spectrum identified as the bandwidth.

The *optical bandwidth* of the fiber cannot, on the other hand, be defined without taking into account the physical length of that fiber. The optical bandwidth of a fiber may be defined as the spectrum presented for use by the physical interconnecting facility (the fiber) itself, separate and apart from the terminal devices. For example, a particular fiber of indeterminate length may be specified to present an optical bandwidth of 100 mHz end-to-end. This simply means that no higher frequency component of any information carried through that fiber, up to 100 mHz in frequency, will be lower in amplitude than 3 dB below the highest amplitude components of the transported information that is recovered from the end of the fiber.

Since the fiber is only one of the lightwave system elements, the other two being the lightwave transmitter and receiver, and since all three elements may affect the system transmission bandwidth, the optical (fiber alone) bandwidth of any system may not be the same as the *information bandwidth* that the composite system presents for use.

It is obviously necessary to establish the required system bandwidth, and once this requirement is known, we have only to assure that no single system element presents less than this required bandwidth. Each discrete element, the transmitter, the receiver, and the interconnecting fiber, must all meet or exceed the system bandwidth requirements.

This is really no different than a conventional coaxial RF broadband system, where all elements, including amplifiers, taps, or splitters, must exhibit transmission bandwidth that does not place limitations on the overall system bandwidth.

System Transmission Bandwidth

System calculations can be made to establish either system rise time or bandwidth. If all system elements are specified in rise time and dispersion, we can calculate the system rise time by squaring all the individual rise times and adding these squared quantities together. The square root of the sum of these squares will then be the Root Mean Square (RMS) system rise time.

For some time, it was generally accepted industry practice to prepare a *rise time* budget for every digital link or system in the manner just described. The end result was the predictable overall digital system performance to be expected. But some system elements are specified by manufacturers in bandwidth units alone, and bandwidth is also a more familiar term to many people in the telecommunications field. So the preparation of rise time budgets has fallen into disuse, and it is now common practice to simply call out bandwidth for all system elements and for overall system performance. This is fortuitous for those more familiar with the terminology and methodology of RF broadband transmission systems as applied in coaxial cable systems throughout the Cable Television industry.

There is a *North American Digital Hierarchy* of digital signals that corresponds to the digital multiplexing of many equivalent voice channels (as telephone circuits perhaps) and a series of digital multiplexing equipments as well, and for information, we include them here as Figures 26-5 and 26-6.

Line Code	*Data Rate*	*Capacity*
T-1 (DS 1)	1.544 Mb/s	24 Chans.
T-1C (DS 1C, 2-DS 1)	3.152 Mb/s	48 Chans.
T-2 (DS 2, 4-DS 1)	6.312 Mb/s	96 Chans.
T-3 (DS 3, 28-DS 1)	44.736 Mb/s	672 Chans.
T-3C (DS 3C, 2-DS 3)	90+ Mb/s	1344 Chans.
T-3D (DS 3D, 3-DS 3)	135+ Mb/s	2016 Chans.
T-3E (DS 3E, 4-DS 3)	180+ Mb/s	2688 Chans.
TX (9-DS 3)	405+ Mb/s	6048 Chans.
TX (12-DS 3)	565+ Mb/s	8064 Chans.

Figure 26-5 North American Digital Hierarchy

Multiplexer	*Inputs*	*Output*	*Output Data Rate*
M 12	4-DS 1	DS 2	6.312 Mb/s
M 13	28-DS 1	DS 3	44.736 Mb/s
M 23	7-DS 2	DS 3	44.738 Mb/s

Figure 26-6 Digital Multiplex Equipment

It may seem incongruous in this text to present information on digital applications, but all of this information will, hopefully, contribute to a better understanding of lightwave transmission systems and their development and applications. In Figure 26-7, for example, we have correlated the standard digital signals with both transmission bit rate in Mb/s, acceptable rise times in ns, and required bandwidth in mHz. This helps understand the relationship of all of these.

		Return to Zero (RZ)		*Non-return to Zero (NRZ)*	
Digital Signal	*Bit Rate (Mb/s)*	*Acceptable Rise Time (ns)*	*Required Bandwidth (MHz)*	*Acceptable Rise Time (ns)*	*Required Bandwidth (MHz)*
DS 1	1.544	226	1.544	453	0.77
DS 1C	3.152	111	3.152	222	1.58
DS 2	6.312	55.4	6.312	110	3.16
DS 3	44.736	7.82	44.736	15.6	22.38
DS 3C	90.148	3.88	90.148	7.76	45.07
DS 3D	135.532	2.58	135.532	5.16	67.77
DS 4	274.176	1.28	274.176	2.55	137.09

Figure 26-7 Rise Time and Bandwidth

Note that the bandwidth presented for use by an optical fiber is a function of the physical length of that fiber, as well as the characteristics of the fiber itself. Thus the units of *fiber bandwidth* are Megahertz (mHz) times kilometers (km), or mHz/km.

In single mode fibers, the bandwidth of a fiber is a linear function of length. Thus a fiber specified to provide 250 mHz/km would provide 50 mHz of usable bandwidth through a fiber length of 5 kilometers (km) per the following calculation:

$$BW_{sys} = \frac{250}{5} = 50 \text{ mHz}$$

Conversely, if we required 50 mHz of bandwidth in a single mode fiber 5 kilometers (km) long, the bandwidth requirement of the fiber would be determined as follows:

$$BW_{fiber} = 50 \text{ X } 5 = 250 \text{ mHz/km}$$

But bandwidth is not strictly a linear function of fiber length in multimode optical fibers. When a fiber is propagating many modes, each mode behaves as a relatively independent transmission channel. The measured system bandwidth is a measure of the lack of equal delay time among these independent modes. If bandwidth were truly a linear function of fiber length, then the calculation shown above for a single mode fiber would apply, but because of the statistical nature of multimode propagation, the *length dependence* is L. Thus the effective length of the 5 km system is 5 km raised to the 0.8 power, which becomes 3.62 km. Since the effective length is shorter, the bandwidth required of the fiber to carry (in our example) the 50 mHz signal will be higher.

Other than calling this to your attention, there is little to be gained by pursuing this further.

In practical applications of optical fibers and lightwave transmission in conjunction with coaxial fiber and RF amplifier broadband extensions, a system often referred to as “hybrid,” since common and familiar terms are used to denote noise and intermodulation distortion, the combinations of such system performances for an overall system transmission quality is quite straight forward, and has certainly been covered adequately in the preceding sections of this text.

Distortion in Analog Systems

Distortion may be defined as the unfaithful reproduction, at the system or device output, of the information or signal that was applied to the device or system input. Some form of distortion is introduced in all transmission systems.

Since our text is directed primarily at Cable Television service, which generally employ analog transmission techniques on a broadband transmission facility, we will focus mainly on the transmission bandwidth that lightwave systems present for use, and the noise and distortion that the optical terminal devices will directly contribute.

We define broadband transmission systems as systems offering substantial portions of spectrum for private allocation or use within the closed system itself. This is opposed to commercial *on air* broadcasting, for example, where public spectrum is used and licensing of frequencies or services is necessary.

Most RF transmission systems in use today for Cable Television service are broadband by nature by this definition. Since lightwave systems may use digital or analog modulation, just as microwave systems may do for example, to incorporate lightwave transmission into Cable Television systems gracefully, we have generally employed them as broadband links.

In fact this evolution, *hybrid systems* including both lightwaves on optical fibers and RF carriers on coaxial cables, seems quite a natural extension of broadband analog transmission. It is reasonable to accept the hybrid combination as one simple broadband transmission system.

If we do so, then our concerns are largely the same as they were in the coaxial broadband transmission systems which we have studied throughout this text. We must be concerned with the transmission bandwidth which such systems present for use, of course, and this bandwidth must be compatible with any coaxial cable extensions. And we must concern ourselves with the terminal devices and their linearity, since this will certainly be a factor in intermodulation distortion that may be introduced. And, of course, we must be concerned with plain old noise as it may be evidenced in the terminal devices.

In RF broadband transmission systems as covered earlier in this text, we learned that some distortion was in the form of intermodulation contributions from the system active devices, such as amplifiers. The terms commonly used were second order beats, triple beats, composite triple beats, etc., and these were a factor of the composite RF energy passed through the unit and the output signal levels that such units delivered. We learned that this composite output could be, and was, directly related to the number of signals (mostly television signals) that were passed through the unit also.

Noise was a function of the Noise Figure (NF) of the units and the input signal levels, and was generally referenced as Carrier-to-Noise Ratio (C/N Ratio).

Distortion in Digital Systems

Most lightwave systems using optical fibers have been employed to date in Telephone systems, and predominately for Telephone trunking service. In such applications there are only two discrete terminals involved, and the requirement is for a multiplicity of rather narrow band circuits (Telephone voice circuits predominately) that terminate at these two locations.

Many of the forms of distortion experienced in lightwave systems lend themselves comfortably to digital signals, and these are evidenced as pulse dispersion or broadening, intersymbol interference, rise times, and the like.

These may, to some degree, also limit the transmission bandwidth of the system, of course. There are any number of texts available for such studies (digital lightwave transmission systems), and we do not propose to pursue such distortion of digital signals in depth here. If our primary concern is analog transmissions and compatibility with conventional broadband coaxial transmission facilities, as they are presently widely utilized in the Cable Television industry, then discussing digital transmission at length may be somewhat inappropriate here. Some comment on lightwave system modulation may be appropriate however.

In digital lightwave systems, the distortion is generally referred to with the term Bit Error Rate (BER). Since the detection is limited to deciding if a pulse is, or is not, present in any particular time slot, the term BER is appropriate.

Modulation

There may be some misconceptions as to digital transmission itself. Any individual signal, be it video or audio, may be sampled and binary bits may be modulated on to any carrier, in fact on to any DC voltage. The result is a voltage or a carrier that is pulsed at a digital rate to reflect this modulation. Such a digitally modulated carrier may be treated as any other modulated individual carrier. It may be transported on any transmission system as an individual signal, just as AM or FM modulated carriers are treated. On a broadband transmission system for example, it can be carried along with other individual signals on a Frequency Division basis, whereby all signals are separated by having different, individual carrier frequencies. Indeed it may even be carried in this fashion along with other, more conventionally modulated signals such as AM or FM signals.

It is also possible to consolidate several individual digitally modulated signals, representing several different and individual pulse streams, into one massive pulse stream at a higher data rate, that is, a higher bit rate of transmission than any single digital signal alone. This process, called *multiplexing*, is accomplished by interlacing the individual pulse streams on a time basis.

Note the distinction of single signal modulation on a digital basis and multiplexing a number of such signals as a single pulse stream or carrier for transportation. These two processes should not be confused. There has been, to the best of our knowledge, no extensive use of digital modulation of single voice channel intelligence for Exchange Telephone service on twisted pairs or, for that matter, on any other transmission facility. Note that we specified single voice channels for Exchange Telephone service.

There have been, of course, many, many applications of several digitally modulated voice channels being consolidated into one, higher data rate pulse stream (or digitally multiplexed) for transportation purposes. There have been, to the best of our knowledge, no extensive use of digital modulation of single channel television signals for widespread distribution and use by subscribers either. Nor has there been any widespread multiplexing of several or many digitally modulated television signals.

This does not preclude the use of digital modulation on individual television signals of course, or the intermixing of such signals with conventionally modulated signals on any broadband transmission facility on a Frequency Division basis.

Then our further discussions of lightwave transmission are directly related to present day Cable Television usage, and are confined to analog modulation of light sources, with individual signals (regardless of modulation) carried, as on a wideband system, as individual, frequency separated carriers. This is analogous to baseband modulation of a microwave transmitter which can accommodate a number of individual carriers as the modulating signal, rather than digital pulsing of the microwave carrier itself.

Thus lightwave links, as employed by Cable Television systems, are generally fully compatible with the existing techniques for signal consolidation in cable system Head Ends, and for carriage of many such television signals on conventional RF broadband facilities such as coaxial cable plant presents.

Lightwave System Terminal Equipment

Terminal equipment is equipment that is installed at points within the lightwave system where the optical transmission terminates. Such points would normally be at the system extremities or at intermediate service locations where a transition is required from lightwave signals to electrical signals. Terminal equipment can be logically subdivided into two categories, those devices that are electro-optical in nature, and those that are entirely electronic or electrical.

The electro-optical category includes all devices that accept electrical input signals and generate or emit lightwave output signals as a result of that input, and those devices that accept lightwave input signals and produce electrical output signals as a result of that input. Typical are laser diodes or light emitting diodes or light sources, and photodetectors of all varieties. Electronic terminal equipment includes devices that process electrical signals only, and typical units might be, in our case, broadband amplifiers.

For discussion purposes it may be convenient to assume that electro-optical and electronic equipments are discrete and separate entities but in actuality, the capabilities and functions of both are often provided within a single product configuration.

Light Sources or Transmitters

In lightwave technology transmitters are *transducers* that convert electrical energy input signals to lightwave energy output signals. This requires a source of light energy. Some sources are light emitting diodes (LED's) and laser diodes. Both are very small semiconductor chips of gallium arsenide (GaAs) or some other material.

The major considerations in the design or selection of light sources are:

Operating Speed. The source must be able to turn on and off fast enough to satisfy the transmission requirements of the system. The speed at which a source can be operated is usually specified in terms of rise time, defined as the time required for a source to affect a transition from 10 to 90 percent of its output power.

Power Output. The source must couple enough optical power into the optical fiber to operate a detector at the distant end of the fiber. The power level must be high enough to overcome the fiber and fiber splicing losses and still provide sufficient light input into the detector to satisfy system signal-to-noise specifications.

Peak Output Wavelength. The wavelength emitted by the source should be stable and should coincide with the low loss band of the fiber to which it will be connected.

Spectrum Width. Ideally, a light source should produce a single wavelength output to eliminate material dispersion in the optical fiber. Most sources emit a number of wavelengths with spectral width usually taken to be 50 percent of the maximum output.

Light Emitting Diodes (LED's)

An LED *Light Emitting Diode* is essentially a p-n junction that spontaneously emits light when current is passed through it. By introducing materials such as indium, aluminum, or phosphorus, the wavelength of the emitted light can be controlled.

The cone of radiation from LED devices is considerably larger than the cone of acceptance of optical fibers. Thus efficient coupling of light output into small core fibers with a low numerical aperture is difficult unless special packaging techniques are employed. Recent developments have resulted in the manufacture of some LED's that can couple usable levels of lightwave energy into even small core fibers.

Although a variety of LED structures can be fabricated, two types of LED predominate today: the *well emitter* and the *edge emitter*, and these are shown in Figure 26-8.

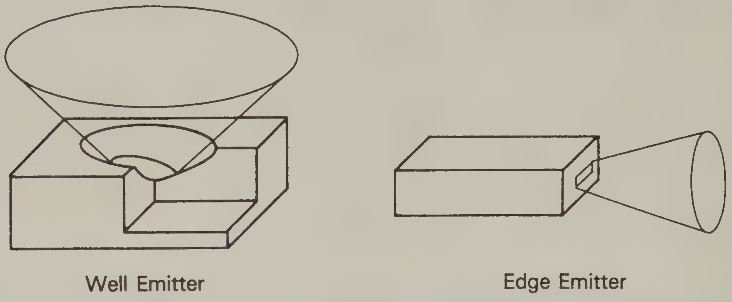


Figure 26-8 Light Emitting Diodes

Well emitters produce light from a surface area fabricated in an open well in the LED. This type of structure generates a widely diverging light beam. Edge emitters produce light from a narrow strip fabricated into the LED material and generate a light beam considerably narrower than a well emitter.

LED sources have the following characteristics:

1. Output power is relatively insensitive to device temperature, which permits devices to be less complex and requires little or no temperature compensation.
2. LED's have wide spectral output.
3. Emission pattern is quite broad, and coupling losses into fibers may be on the order of 10 dB or higher.
4. LED's are generally considered to have long operating life.
5. LED's are generally inexpensive.
6. LED's have a rather large active area where light is generated and have characteristically high capacitance. This makes them difficult to digitally modulate at higher transmission bit rates.
7. Since LED light power output is relatively linear over a rather wide range of input drive current, LED's are particularly well suited for analog modulation systems.
8. LED's typically have lower light power output than lasers.

For the above reasons, LED's are best suited for lower bit rate applications or shorter length systems where many of these deficiencies are not particularly significant. The use of large core multimode fibers may find many advantages in limited length links within machines or vehicles, for example. In such cases, the broadband emission pattern of the LED's might not be inhibitive.

Laser Diodes

The term laser is derived from *Light Amplification by Stimulating Emission and Radiation.* The laser structure provides an "optical cavity." A laser functions much as an LED until a threshold drive current level is reached. At this point incident photons created in the recombination process (the same as in the LED function) stimulate the emission of additional photons within the optical cavity in a process called *lasing*. A typical laser structure is shown in Figure 26-9.

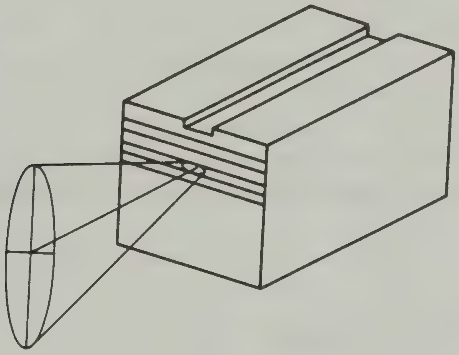


Figure 26-9 Laser Diode

As the device temperature increases, the threshold current increases, and the optical output power changes. The wavelength of the optical output is temperature dependent also. Thus lasers are significantly more complex than LED's in that some form of temperature sensing and compensation is required.

One technique employed involves *thermoelectric cooling*. A thermoelectrical cooler (TEC) is not a simple heat sink. When electrical current is passed through it, one side becomes warmer and one side cooler. By sensing the temperature of the assembly with a thermistor, the laser temperature can be controlled and stabilized. A thermoelectric cooler is shown in Figure 26-10.

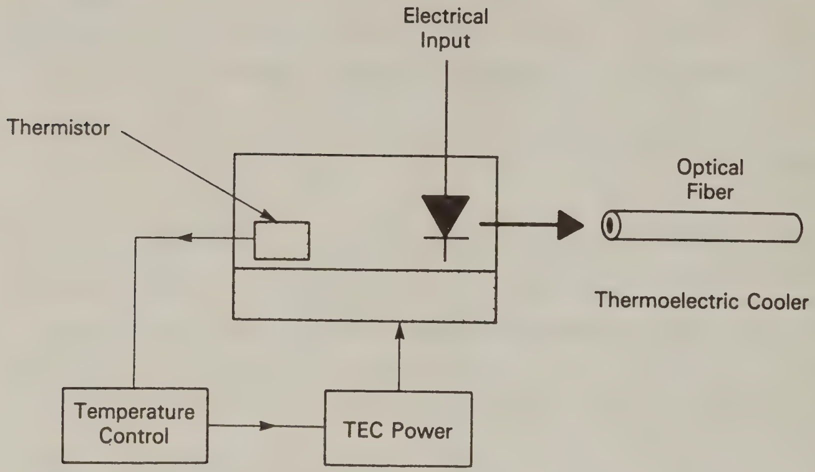

Electrical Input
Thermistor
Optical Fiber
Thermoelectric Cooler
Temperature Control
TEC Power

Figure 26-10 Thermoelectric Cooling

In addition to temperature stabilization, most lasers incorporate some *laser bias* control to stabilize the threshold current itself, which otherwise might change with temperature and device aging. Bias control is shown in Figure 26-11.

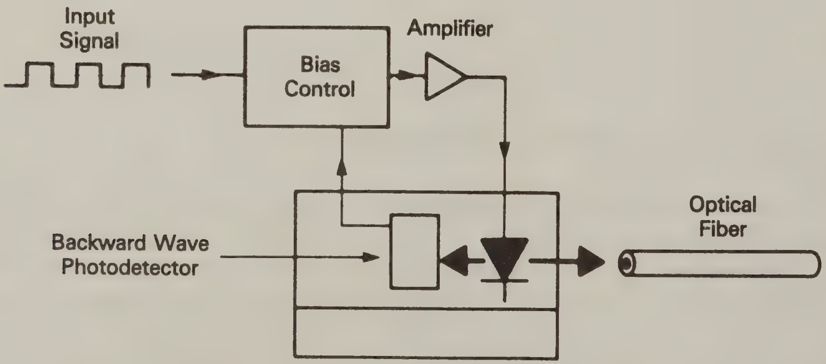

Input Signal
Amplifier
Bias Control
Optical Fiber
Backward Wave Photodetector

Figure 26-11 Laser Biasing

Obviously these stabilizing functions add to the sophistication and cost of laser diode light sources.

Laser light sources have the following characteristics:

1. Output power is temperature dependent and requires that sophisticated temperature compensation be built into the device.
2. Output wavelength is also temperature dependent.
3. Threshold current must be controlled by monitoring light energy output power.
4. Lasers typically produce some optical output all of the time, due to the fact that they are maintained at a bias above the lasing threshold current to avoid having to operate in the threshold current region.
5. Lasers typically have higher output power than LED's.
6. Lasers have very narrow beam width output that facilitates coupling output energy into small core optical fibers.
7. Lasers have very narrow, almost *monochromatic* spectral width output, so all of the light output is at the same wavelength or nearly so. Due to this feature, material dispersion within the optical fiber is minimal.
8. Lasers are more expensive than LED's.
9. Lasers are generally considered to have shorter operating life than LED's.
10. Lasers, having shorter rise times, make it easier to modulate them at higher transmission bit rates.

For the above reasons, lasers are the most suitable choice for systems with high bit rates, or long length facilities where single mode fibers are employed.

Lightwave Detectors or Receivers

In lightwave technology, lightwave receivers are transducers that convert lightwave energy input into electrical energy output signals. Receivers process the electrical output of an internal photodetector by amplifying, pulse reshaping, or effecting current to voltage conversions such that the electrical output is compatible with the system in which the receiver is employed.

At the present time, photodetectors are largely limited to *positive-intrinsic-negative (PIN)* diodes or *avalanche photodiodes (APD's)*. The major considerations in the design or selection of lightwave receivers and photodetectors are as follows:

Responsivity. *Responsivity* is a measure of a detectors output voltage in relation to the optical input power.

Quantum Efficiency. *Quantum efficiency* expresses a diode's sensitivity as the ratio of photons impinging on, to the number of electrons flowing in, an external circuit. An efficiency of 1, or 100 percent, would mean that every photon sets one electron flowing.

Dark Current. Even in the absence of incident light, some current flows because electron-hole pairs can be generated thermally. *Dark current* is device temperature dependent, and also called leakage current.

Noise Equivalent Power (NEP). NEP is the RMS signal power required to produce a signal-to-noise ratio of unity. It is the minimum induced optical power required to create a current equal to the inherent RMS noise current, and is analogous to thermal threshold of detection in receivers in other technologies.

Response Time. The *response time* of a detector is the time it takes the electrical output to rise from 10 percent of peak output to 90 percent of peak output. Such time might be on the order of 1 ns for an APD and perhaps 3 or 4 ns for a PIN detector, and in either case is dependent upon bias voltage.

Bias Voltage. Operating with a current, a detector requires a *bias voltage*. PIN devices typically require less than 100 volts, where APD's might require several hundred volts. Since bias voltage influences response time, dark current, and responsivity, and can increase device temperature, it can significantly affect detector operation.

Although this text is not concerned with the specific design of detectors or lightwave receivers, it may be useful to describe some basic detectors here.

PIN Diodes

A PIN diode consists of a negative and a positive terminal separated by a *depletion region*, created by reverse biasing so that very little current flows through the device. Electrons tend to migrate from the negative terminal, and to form *holes* near the positive terminal, depleting the area around the junction of carriers. Thus the reference to the depletion region.

When incident light impinges on the diode, the photons absorbed create electron-hole pairs in the depletion region. Then carriers separate and drift toward their respective terminals, and for each electron-hole pair created, an electron is set flowing in the external circuitry.

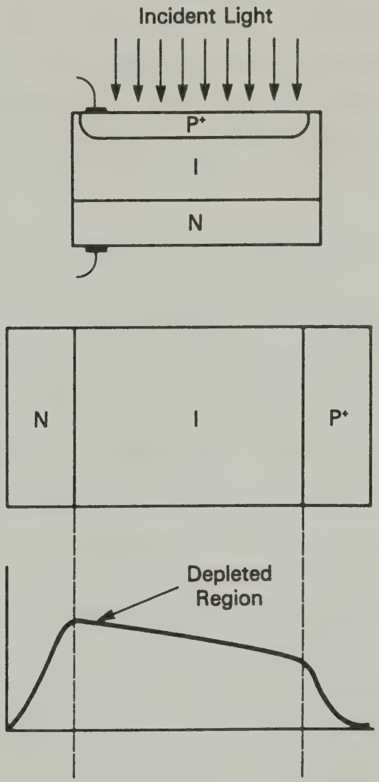


Figure 26-12 PIN Diode

In an ideal PIN diode, each incident photon creates one electron-hole pair, which in turn sets one electron flowing in the external circuit. If the light flux impinging on the diode is weak, the electricity generated may not be strong enough to be detectable in the presence of the noise that is inherent in the PIN diode and the receiver circuitry.

PIN diodes have the following characteristics:

1. A relatively simple structure compared to APD's.
2. They are relatively insensitive to device temperature.
3. Quantum efficiency, that is, photon-to-electron conversion gain, is typically 1 or less.
4. They have a limited dynamic range.
5. They have high reliability and long operating life.
6. They are inexpensive.
7. Compared to APD's, they have low responsivity for a given signal-to-noise ratio.

Avalanche Photo Diodes (APD's)

When the light flux impinging on the detector is weak, it is desirable to increase the photodetector output before any processing or amplification is attempted within the electrical sections of the receiver. This detection gain can be accomplished through the use of an APD, which is shown in Figure 26-13.

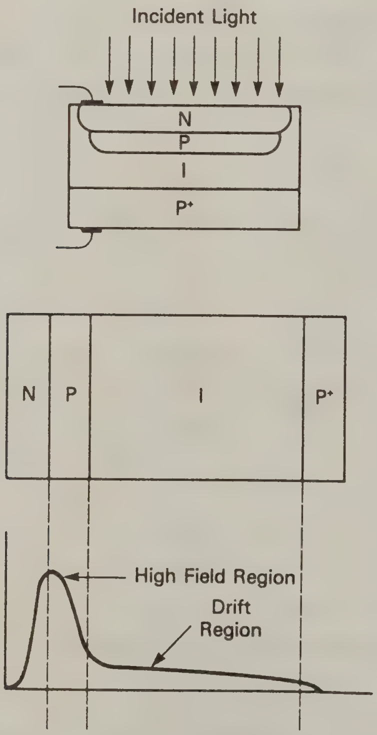


Figure 26-13 Avalanche Photo Diode (APD)

The APD establishes a strong electrical field within a portion of the depletion region as shown by the depletion region profile in the drawing. Primary carriers created by incident photons (as in the PIN diodes) that enter the strong field can gain several electron volts of energy. In a collision with the lattice structure, the primary carrier loses enough energy to promote an electron from the valance band to the conduction band in a process known as *collision ionization.*

The secondary carriers may, in turn, create even more carriers. The result is a phenomenon known as *avalanche* breakdown, evidenced as internal gain.

The number of electrons set flowing in the external circuit of an APD is equal to the number of incident photons times the device's multiplication factor. An APD may produce a photon-to-electron conversion gain on the order of 3 or 4, although it may also produce a higher noise output.

APD's are sensitive to device temperature, so Automatic Gain Control (AGC) is usually included, to maintain a stable bias voltage as the temperature varies. Thus receivers using APD's are generally more complex and expensive.

APD's have the following characteristics:

1. They are more complex in structure than PIN diodes.
2. Their responsivity is sensitive to device temperature.
3. Their quantum efficiency, and thus their photon-to -electron conversion gain, is on the order of 3 to 5.
4. They usually present an extended dynamic range.
5. They are highly reliable and have a long operating life.
6. They are more expensive than the simpler PIN diodes.
7. Their resposivity is better than the PIN diode detectors. A typical improvement over the PIN diode is 5 or 6 dB.

Lightwave Receiver Design

It is not necessary that applications engineers or operating technicians master the details of optical sources or detectors, but it does help to realize that to ensure adequate detection, generally the optical input signal level should be at least twice the inherent receiver noise current.

More optical power input may be necessary to provide a desired signal-to-noise ratio or, in the case of digital applications, a required Bit Error Rate (BER). In a sense, this is analogous to the relationship between input signal level and Noise Figure (NF) in conventional RF broadband analog transmission systems, as discussed earlier in this text.

To reduce the effects of noise, a transimpedance amplifier is included in some receiver packages. Such receivers using a PIN diode detector are sometimes called PIN-FET units. FET refers to a *field effect transistor* employed to amplify the detector electrical output signal.

Because detector active surface areas are relatively large, efficient coupling of light from an optical fiber into the detector is not difficult. Sometimes fibers with a core area larger than the core sizes used in the link are utilized as detector *pigtail* fiber inputs, to minimize receiver light coupling losses.

Usually PIN diode packaging is simpler than APD packaging. The latter can be quite complex, particularly if a device cooler (TEC) is included.

Terminal Equipment Applications

Because a laser couples the most light into a fiber, and because an APD detector is most sensitive to weak optical signals, these offer optimum performance in high bit rate digital, or longer distance applications. The higher cost and complexity of such devices may be more than offset by the elimination of an expensive intermediate repeater. At the transmission distances usually encountered in Cable Television distribution systems however, repeaters are rarely required or mandated, and the unique characteristics of these devices do not automatically qualify them to be the best solution for every application.

An analogy might be drawn with microwave transmission systems. Some transmitters employ a *klystron* tube, providing significantly higher RF output then other, completely solid state units. Clearly the higher RF output signal provides more transmission path *fade margin* and this might be considered to be inherently superior. Consider, however, that the microwave path was only nominal, or even very short.

The microwave link design might provide an adequate fade margin in other ways, perhaps in antenna size and gain. If this were practical, the reduced cost and complexity of completely solid state microwave transmitters might be very attractive indeed. The application must be considered in the decision-making process, and this is certainly true in the design of lightwave transmission systems also.

It can be shown that even using multimode fiber, with a significant contribution od modal dispersion, a transmission system using a data rate of 45 Mb/s would not be bandwidth limited until the fiber length was on the order of 40 km or so. In such a case, the rise time characteristics of the light source and detector become somewhat academic. Stated another way, in such an instance, an LED source and a PIN detector might function quite satisfactorily.

This kind of installation would primarily be attenuation limited. It might be necessary to specify a laser light source to provide adequate light input to the receiver, and it might be necessary to specify and use an APD detector as well, if the interconnecting fiber length, or the fiber loss, so dictated. It might also be possible to select a lower loss fiber, or a different operating wavelength, or to consider the combination of a laser source and a PIN detector, instead of an LED source and an APD detector. The link design problem in this case resolves itself to transmission losses and levels alone.

It may be useful to briefly review the specifications of lightwave terminal equipment that would be of primary concern in the design and selection process.

Summary

Distortion and noise have different terms and different units of measure in analog or digital lightwave systems. Conversions between system calculations done on a rise time basis or on a bandwidth basis are possible, but since manufacturers now specify equipments and fibers in terms that are compatible with coaxial broadband applications, the inclusion of lightwaves into coaxial plant is quite straight forward.

Light attenuation in optical fibers due to light scattering or light absorption are present, but follow the conventional processes of both. Fibers are susceptible to other mechanical light absorption mechanisms such as micro-bending during fiber or fiber cable fabrication, and during placement of cables as well.

Optical transmission levels are stated in dBm with 0 dBm referenced to 1 milliwatt. Optical losses in fibers, splices, or other optical devices are stated as a power ratio in dB.

In analog lightwave systems, fiber loss is a function of fiber length as well as fiber structure and fabrication.

Intermodulation distortion is a function of the composite signal carried (may be the number of television signals present) and the lightwave output signal level delivered to the optical fiber for propagation. Noise is a function of the receiver design and the lightwave signal level provided at the receiver input.

For analog applications, specifications for terminal equipments and optical fibers are usually in the same terms or units that are used for RF broadband coaxial technology, as covered in the preceding portions of this text.

Chapter 27

Optical Cables and Devices

There are a variety of ancillary devices that can be fabricated and employed for use in lightwave transmission systems. These devices permit us to configure systems in various ways to best accommodate different conditions or applications.

Defining Optical Devices

As used here, the term *optical devices* denotes devices whose basic functions derive from optical principles and techniques. Such devices directly process light rays by focusing, filtering, collimating or otherwise handling the light rays themselves. Their use in lightwave systems will thus be confined to the optical transmission path that is established between two or more terminal points at which electro-optical devices are located to generate or detect the lightwave signals.

Many of these optical devices present the same functional capabilities of comparable units employed in other kinds of transmission such as filters, power splitters or dividers, or service point taps used in multi-pair metallic or coaxial cable systems. Some of these devices do not require operating power to perform their functions, and we generally refer to such units as *passive*, as opposed to *active*, power consuming devices.

Although lightwave energy is electromagnetic energy that travels in a wavefront just as radio or microwave energy does, the much higher frequency (shorter wavelengths) require that optical mechanisms and techniques be employed. Some of the common phenomena we have become familiar with in earlier experiences will be less applicable at these wavelengths. For example, in conventional metallic cable systems, impedance matching at cable and device interfaces must be considered to assure the efficient transfer of energy and to minimize possibly disruptive energy reflections from the interface.

This is true even of cable ends which must sometimes be terminated in the characteristic impedance in order to inhibit reflections. In theory, the same constraints apply to lightwave transmission, but the mechanisms involved are less reflective. Although lightwave energy reflections do occur from an open end of an optical fiber, the amplitude and time delay of the reflected energy is such that no specific protective action is normally necessary.

Conversely, the connection of two fiber ends (as in a fiber splice) presents more severe optical problems than an equivalent metallic conductor splice. With fibers, the interface at a fiber splice becomes largely a mechanical problem involving fiber core size, alignment of the two ends, ellipticity of the two fiber cores, etc., to ensure a minimum of reflection and a maximum transfer of light energy. In optical connections, irregularities of this type are more seriously evidenced as a loss of lightwave energy than as a disruptive reflected signal.

In optical devices, additional and possibly disruptive optical interfaces are frequent, varied, and sometimes unavoidably introduced. For example, when mirrors, prisms, or diffraction gratings are employed, additional glass-to-air or air-to-glass interfaces cannot always be avoided. Each of these individually can introduce Fresnel reflection losses and other problems. In such devices the mechanical construction and geometry can have a significant effect on the transmission characteristics of the unit.

Optical Components

Prisms have properties that refract light rays, and so they can be used to separate different wavelengths of lightwave energy. Thus they could be employed in optical devices to filter out signals of different wavelength. It is also possible to utilize several prisms in an *optical switch* that could direct lightwave energy into one or more optical fibers selected by mechanically altering the physical relationship of two or more prisms. Or an optical switch can be fabricated so as to mechanically reposition the ends of fibers to selectively direct the light into particular fibers. Optical switches of either type would require electrical energy to reposition optical elements perhaps, but not to directly effect the actual transfer of lightwave energy.

Mirrors are an obvious optical component and are fabricated in many forms including elliptical and parabolic varieties. Through mirrors, light may be focused and directed as necessary.

Another optical technique employs *dichroic filters*. Dichroism is the property a surface has of reflecting light rays of one wavelength while passing light rays of a different wavelength. Figure 27-1 shows how a dichroic filter may be employed in practical optical devices.

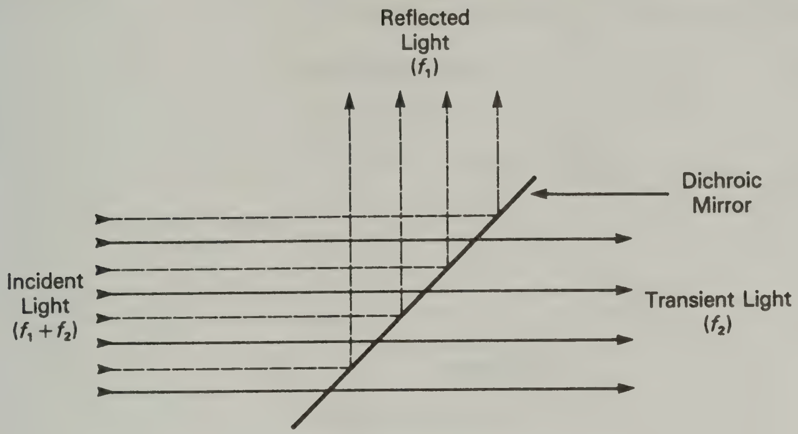

Reflected
Light
(f_1)
Dichroic
Mirror
Incident
Light
($f_1 + f_2$)
Transient Light
(f_2)

Figure 27-1 Dichroic Filter

It is also possible to etch or score a grating or number of parallel lines on an optical surface that will diffract light rays of a particular wavelength while passing other wavelengths. Figure 27-2 shows a *diffractive grating* employed as a filter, and this mechanism is often encountered in practical optical devices today.

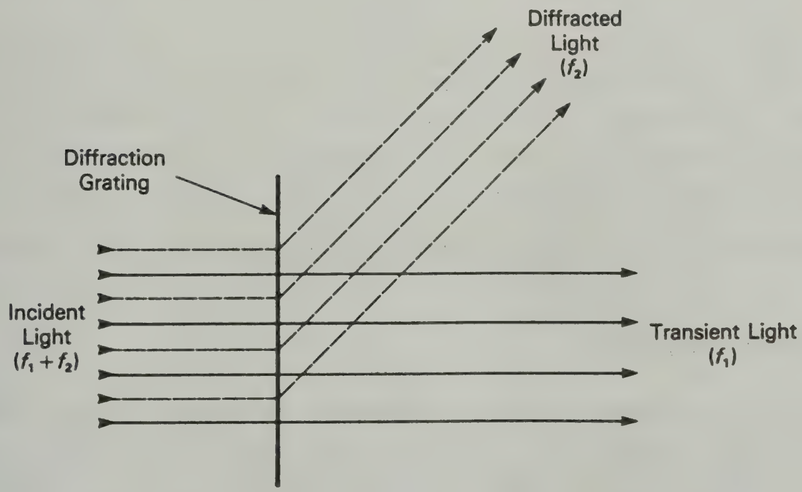
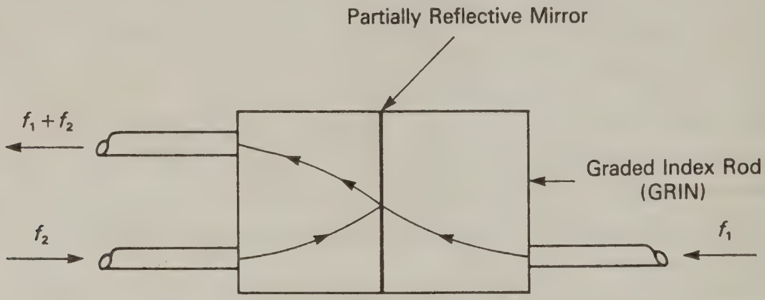
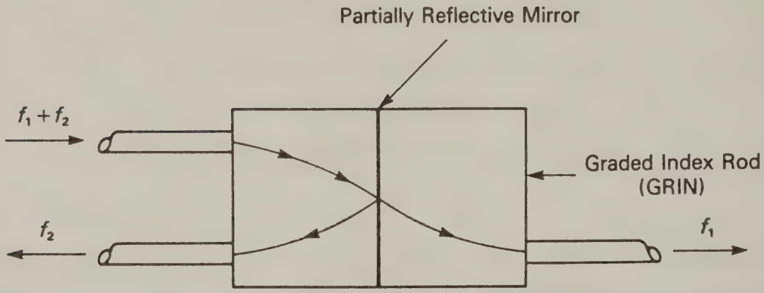

Diffracted
Light
(f_2)
Diffraction
Grating
Incident
Light
($f_1 + f_2$)
Transient Light
(f_1)

Figure 27-2 Diffraction Filter

In applying optical principles, any number of lenses can be fabricated to focus, collimate, or otherwise process light rays. Combinations of filters and lenses are also possible, as shown in Figure 27-3.



Multiplexing



Demultiplexing

Figure 27-3 Graded Index Filters (GRIN)

In this figure a glass rod, essentially a section of a graded index fiber structure with optical lensing properties, is combined with a partially reflective surface (a *dichroic mirror*) that allows one wavelength to pass through it while reflecting a different wavelength. The geometry of this unit is such that the reflected rays are focused on a point where a separate fiber is positioned. The light entering the glass rod at any point other than along the axis is reflected back toward the axis at the middle of the section of rod.

Fabricated Optical Devices

Instead of the discrete optical mechanisms described, optical devices such as *couplers* and *splitters* can be made using optical fibers alone. The technique is to twist the fibers together, taper them somewhat by elongation, and then fuse the glass into a single, solid structure. Such units might be referred to as *bi-conical* or tapered fused units.

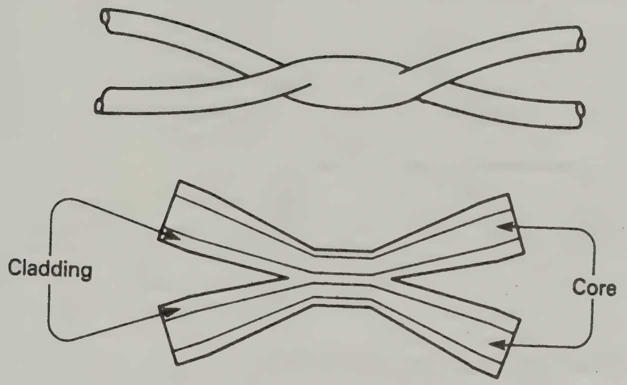


Figure 27-4 Bi-conic or Tapered Fused Couplers

Figure 27-4 shows a four terminal bi-conical device. Note that along the fused cross-section, the cladding materials have been fused together and the two fiber cores are separated by only one common cladding. Light energy within this common cladding is shared between the two fiber cores by power splitting or coupling, and is recaptured through the common cladding by combining.

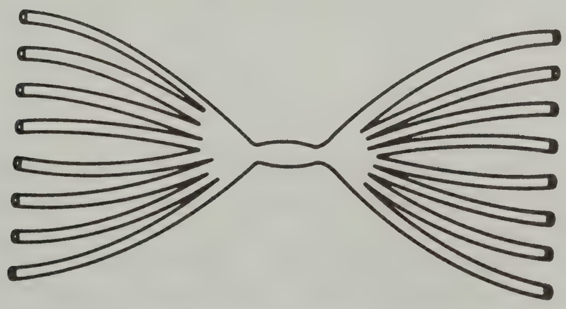


Figure 27-5 Fused Star Coupler

The use of bi-conical devices can be extended to a relatively large number of fibers permitting so-called *Star type network* configurations to be built up, as shown in Figure 27-5. Light can be coupled from one fiber into many, or from many fibers into one.

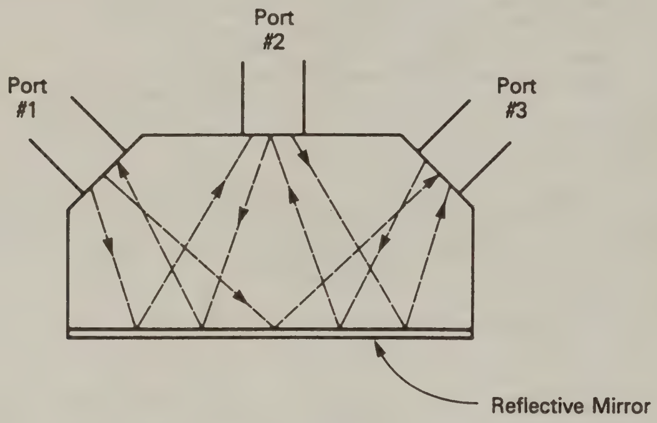


Figure 27-6 Reflective Star Coupler

Star type couplers may also be constructed by using reflective mirrors in discrete components, as shown in the three-port device in Figure 27-6. Any light rays injected into the coupler from any port will reflectively propagate and appear on any optical fiber connected to any of the other ports.

The analogy of optical couplers and splitters with splitters and directional couplers in coaxial cable systems is quite obvious, and various amounts of signal distribution is possible, just as is the case in coaxial Directional Couplers as covered earlier in this text.

Optical Service Taps

Taps are devices that permit a multiplicity of service points to be established along the length of a transmission system for use by the subscribers to that service. In the coaxial systems that we are familiar with in Cable Television service, subscriber taps are ubiquitous and clearly understood. Lightwave systems on optical fibers may also be tapped for service, and could extend lightwave energy to subscriber terminals. In such an application, the taps would couple light energy out of the transportation fiber and into the subscriber premises as lightwave energy on service drops that were, in themselves, optical fibers also. And taps and service drops can be bi-directional also, providing signals both out of, and back into, the backbone transmission system.

A passive, one way *optical tap* might be configured as shown in Figure 27-7.

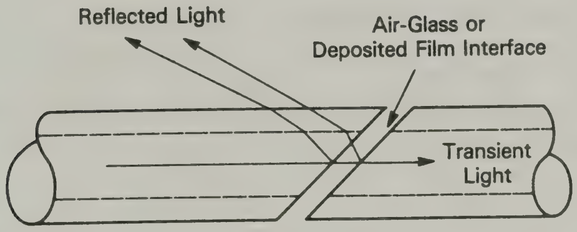

Reflected Light
Air-Glass or
Deposited Film Interface
Transient
Light

Figure 27-7 Passive Optical Tap

In the figure, the thickness of the deposited film or the air-glass interface could be varied during fabrication to determine the amount of lightwave energy that is actually coupled on to the output tap port. This would determine the amount of energy that remains available at the "through" port as well as the amount of energy actually provided to the service drop itself. This is the same basic technique used in RF taps in coaxial cable transmission, as we have learned earlier in this text.

We could fabricate *active taps* as well, which would detect and convert the signals on the backbone fiber into electrical signals to feed the subscribers service drop. We show such a device in Figure 27-8.

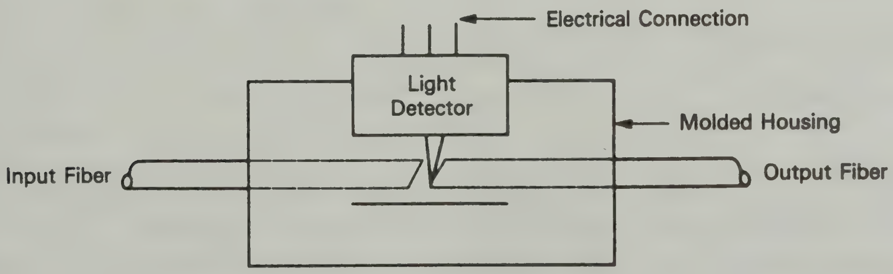

Electrical Connection
Light
Detector
Molded Housing
Input Fiber
Output Fiber

Figure 27-8 Active Optical Tap

Tapping Lightwave Systems for Subscriber Service

Of course if such tap devices were available and widely used in lightwave distribution systems as coaxial plant is presently configured, then optical taps, available in a variety of values, would be discrete units just as coaxial subscriber taps are. Such optical taps would have to be cut into (spliced into) the backbone transportation fibers, and this could introduce many, many optical splices or connectors, each introducing some loss, and each introducing some uncertainty as to long term reliability. In the case of active taps, we would also have to power these devices somehow.

Passively optically tapping a fiber many times, as we are required to do for the distribution of Cable Television service, would require optical fiber service drops of course, and since the light energy levels are rather low, the insertion of many taps with the associated distribution of signal, is not practical. By the way, in such systems we would have to detect and convert lightwave signals to electrical signals to feed the subscribers television equipment at each and every station served. Certainly this would distribute sophistication throughout the system, and would increase costs at the lowest common denominator, the subscriber station.

If, on the other hand, we used active taps and detect and convert light signals to electrical signals at every service drop location, we have to power these units, and there would be a proliferation of such complex and costly devices.

To our knowledge, there are few if any Cable Television systems that extend lightwave signals to each subscriber premises. What is widely done is to construct what we will call *hybrid systems*, where lightwaves are used on fibers to arterially distribute signals throughout an area, and then transitions to RF broadband coaxial plant are made. These transitions do not involve demodulation of the lightwave signals and remodulation of the RF coaxial signals. The process is more a *hetrodyne* to lower frequencies for extension through the coaxial plant for distribution to subscribers.

In hybrid systems, the lightwave receivers are *strand mounted* as die cast housings, and are *cable powered* also, just as conventional RF amplifiers are now. The efficiency of subscriber tapping on coaxial systems is well established and was covered quite thoroughly earlier in this text.

Of course the cascade of serially connected RF broadband amplifiers is strictly limited in hybrid systems to three or perhaps four such amplifiers, and in such cases, those amplifiers may well provide somewhat higher gain and somewhat higher distribution coverage per amplifiers as well. This is possible because we have limited the sources of noise and intermodulation distortion to only a few devices, in this case a lightwave transmitter, a lightwave receiver, and 3 or 4 analog RF amplifiers. Since there are fewer contributing devices, the contribution from each such device may be somewhat higher and the composite contribution may still be quite tolerable.

Optical Fibers

Optical fibers are *light guides* through which light rays will propagate. One way of classifying optical fibers is by the material they are constructed from. There are *plastic fibers*, glass core, plastic cladding fibers, and a variety of types of glass in all glass fibers. Most of the fibers that have been used to date in telecommunications systems are made of *silica glass*.

The physical dimensions of optical fibers are very small, with outside diameters of 125 um or so being typical, perhaps. Although glass as a material may have greater strength than metallic wire of comparable size, the inherent strength of glass depends on the absence of stress-producing chemicals or physical defects in the glass itself.

Flaws in optical fibers that may be introduced during fabrication, handling, placement, or even exposure to the atmosphere, all represent points of potential fiber failure. A fiber once flawed may be further degraded by stress corrosion, and the defect may expand or grow. Moisture, mechanical stress, and chemical attack can all accelerate stress corrosion in optical fibers.

Because of their small physical size, and the mechanisms of light propagation through them, optical fibers are inherently more vulnerable to defects than metallic conductors. A metallic conductor may experience minor surface abrasion during handling, but the impact on transmission through that conductor will be negligible compared to the effect of that same defect in an optical fiber.

Optical Cable Considerations

In the design of cables containing one or more fibers, a major objective is *isolating* each glass element (a fiber) from any and all stresses, if at all possible. This includes stress due to moisture as well as the mechanical stress that cable placement and normal thermal expansion and contraction of other cable materials may introduce.

There are unique vulnerabilities in light guides that necessitate meticulous attention to *stress relief* in fibers. For example, the phenomena of *micro-bending* and *macro-bending* are not common considerations in metallic cabling technology.

Micro-bending may be defined as small abrupt changes in the optical fiber core mechanical structure, or sharp irregularities at the interface between the fiber cladding and the core material, as shown in Figure 27-9. Such irregularities may be minute, but they may still introduce some significant additional attenuation to light transmission through the fiber. Micro-bending may be introduced during the fabrication processes.

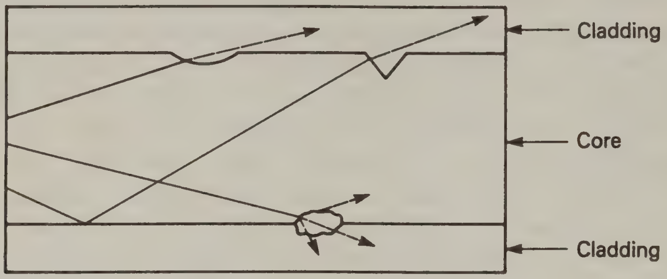


Figure 27-9 Micro-bending

Macro-bending occurs when a fiber bend radius decreases to the point that light rays within the core start to escape into the cladding material, as shown in Figure 27-10. The radius at which macro-bending occurs depends upon the fiber type and size, and the operating light wavelength. Longer wavelengths are more susceptible to losses due to macro-bending.

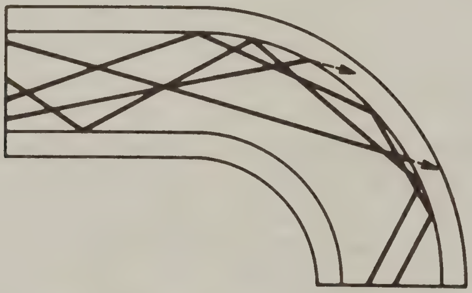


Figure 27-10 Macro-bending

In the design of multi-pair metallic conductor cables, the size, strength, and number of conductors involved can impart substantial strength and anti-buckling qualities to the cable structure. This is not the case in fiber cabling. Now the design problems are complicated by the necessity to isolate each fiber from the cable structure to some degree.

For example, to avoid transferring stress to optical fibers, *excess fiber* length must be provided per unit of cable length to accommodate fiber bends and thermal excursions. In effect, the fibers must be free to move within the confines of the cable structure at a different rate, and perhaps in a different direction, than the rest of the cable material moves.

Before addressing the complexities of fiber cabling, some level of protection for each individual fiber alone must be provided. Most fibers are individually coated with one or two *polymeric coatings*, typically 65 to 185 um in thickness, to provide some protection against macro-bending and to permit fiber handling. Generally it is necessary to remove these coatings either mechanically or chemically before any fiber splicing or connecting is undertaken.

Fiber Buffering Protection

Over and above the coating process, in many cable structures it is advisable to provide additional fiber protection against stress, moisture, or chemicals. This can be done by encasing each individual fiber within an *annular buffer* tube. In Figure 27-11 we show one technique generally referred to as a *loose tube*. Here, the protective jacket or tube is substantially over sized compared to the outside diameter of the coated fiber. This allows considerable freedom of fiber movement within the tube, as shown in the three parts of the drawing, and it also allows excess fiber length to be accommodated.

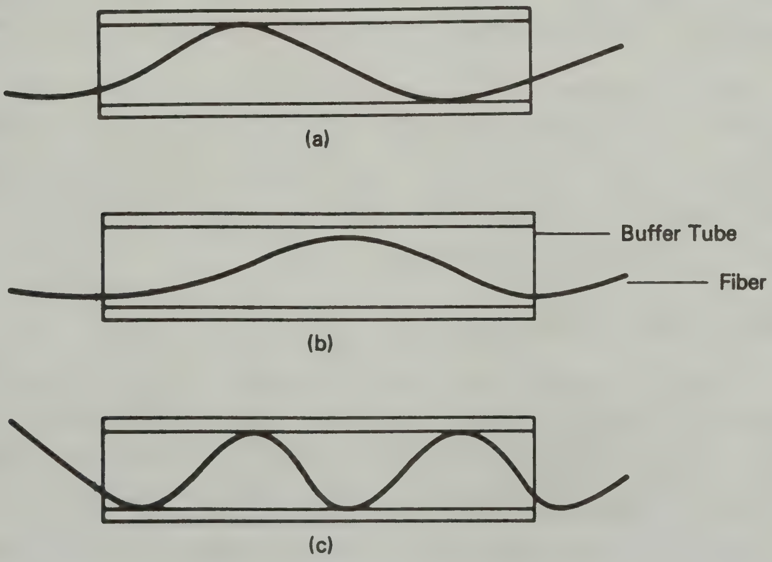


Figure 27-11 Loose Tube Buffering

The tube material itself provides some lubrication for the independent fiber movement, and the tube may be *flooded* with an elastic compound or gel to inhibit the entry of moisture.

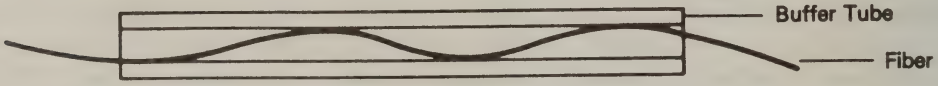


Figure 27-12 Tight Tube Buffering

A different buffering technique is shown in Figure 27-12. In *tight tube buffering*, the inner diameter of the tube is only slightly larger than the coated fiber outside diameter. In feel and appearance, this configuration might resemble a plastic insulated metallic conductor in a conventional multi-pair cable.

The earliest tight tube buffer techniques used buffer materials that were not closely compatible thermally with the optical fiber itself. Consequently, when the buffer tube contracted due to thermal changes, some stress was transferred to the fiber. This problem has been largely resolved in later cables by selecting buffer material that is more thermally stable and compatible with the fiber.

Note that in Figure 27-12, the tight buffering tube cannot accommodate much excess fiber length, although it does actually allow some independent movement of the fiber within the tube. To offset this, in cabling using tight buffering for fibers, the lay or helical serving of the fibers throughout the length of the cable is closer or tighter, to provide extra fiber length within any discrete cable length.

Optical Cable Design Objectives

As in metallic conductor cable design, the fiber cable structure is intended to protect relatively fragile fibers from mechanical damage and exposure to moisture and chemicals. The design must also provide sufficient strength and rigidity for the fibers to survive normal cable handling during placement, and long term exposure to the environment. Many of the materials and manufacturing techniques that have evolved for metallic conductor cables find direct application in fiber cables.

The major differences in the design problems for each is the increased necessity in fiber cables of isolating the fibers themselves from any stresses that may develop within the cable structure.

Essentially, today's fiber cables incorporate only two basic structural designs. The first structure provides a protective core void or tube throughout the cable length by means of the cable architecture. This space or core in the center of the cable is not greatly different in function than a separate cable conduit would be. The optical fibers are placed within the core as a part of the cable fabrication process, not "pulled in" to the conduit at a later time as a separate work operation. The cable architecture relies entirely on the outside wall structure of the cable to provide mechanical strength for cable pulling and placement, and for sufficient rigidity to avoid cable buckling. This might be characterized as providing a thick walled construction.

The second basic cable structure more closely resembles conventional multi-pair cable designs in that individual fibers retain their identity and individuality within the overall structure, just as metallic pairs do even though they may be stranded together in bundles. Typically, cables of this type include a so-called *strength member*, which may be made of any of several materials which occupy the center of the cable structure. The optical fibers are grouped around this element. Various levels of protection can be designed into the outer wall of such a cable, including metallic moisture barriers, several extruded jackets, and armor tapes.

Ribbon Cable Structure

Figure 27-13 shows a conduit type of cable which has become known as *ribbon cable.*

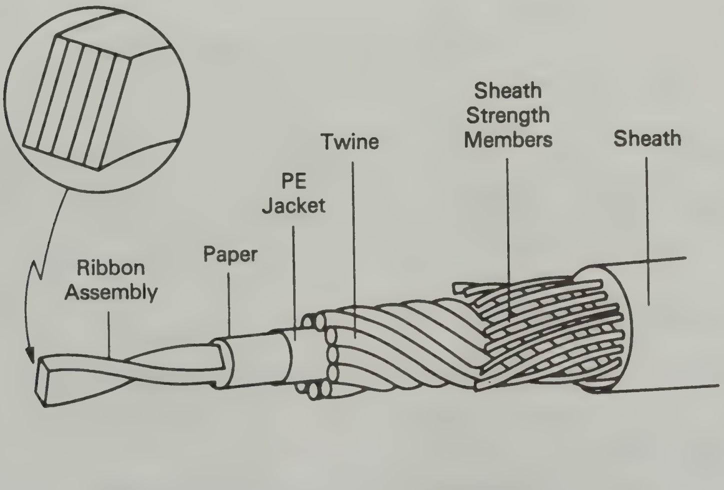


Figure 27-13 Ribbon Cable Structure

Note that here all fibers are positioned within the core space provided in the center of the cable. Individual fibers are assembled into a parallel relationship and then encapsulated into a flat ribbon type of construction that becomes an integral cable assembly. A ribbon of this type may contain as many as twelve individual fibers, and several or many ribbons can be stacked as a single mechanical assembly. The ribbon assembly is spiraled or helicaly served through the length of the cable to provide extra fiber length, and thus avoid stress. The core void enclosing the ribbon is often flooded with a moisture-excluding compound or gel.

One unique aspect of these high-fiber-count cables is a companion method for splicing single ribbons in a single work operation, not individual fibers, but an entire ribbon in one operation. Figure 27-14 shows a mechanical splice technique used with ribbon cables of this type.

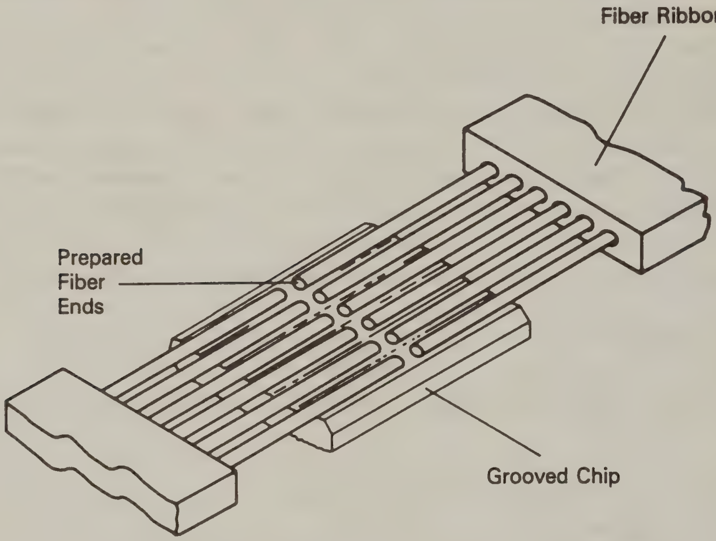


Figure 27-14 Ribbon Cable Splicing

In general, ribbon cable is expensive to fabricate, and to date the configuration has been limited to high-traffic-density cable routes connecting major population centers where a larger number of fibers might be required.

Strength Member Structure

Figure 27-15 shows a cable that uses a *strength member* type of construction. The so-called strength member, which may be made of several different materials, occupies the center of the cable structure, and the optical fibers are grouped around this element.

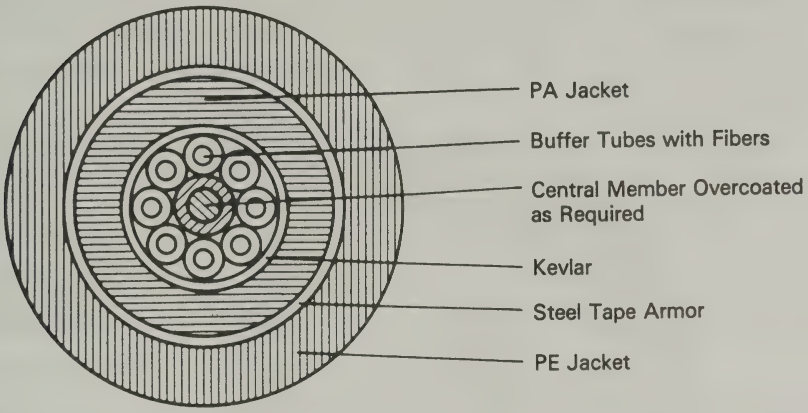

PA Jacket
Buffer Tubes with Fibers
Central Member Overcoated as Required
Kevlar
Steel Tape Armor
PE Jacket

Figure 27-15 Strength Member Structure

Various levels of protection can be designed into the outer wall of such a cable, including a metallic moisture barrier, several extruded jackets, and armor tape.

Although the center member is often called a strength member, it usually does not provide all or even most of the cable mechanical strength, although it does serve to inhibit fiber or cable buckling when the cable is bent or flexed. Some variations on this type of construction do not provide a centrally located strength member at all, but instead cluster the coated and individually buffered fibers along the axis of the cable, as shown in Figure 27-16.

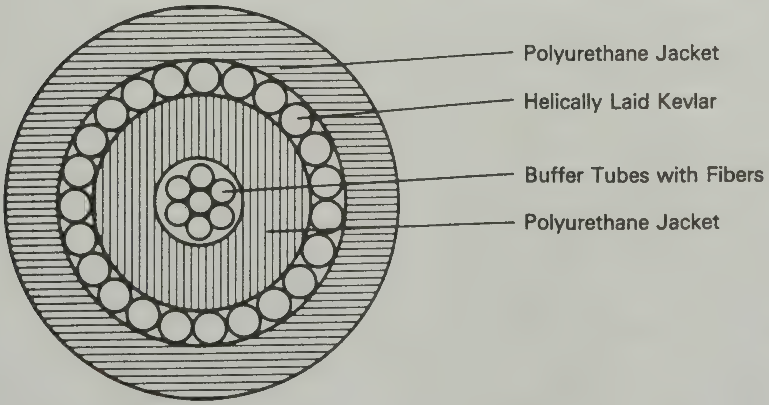

Polyurethane Jacket
Helically Laid Kevlar
Buffer Tubes with Fibers
Polyurethane Jacket

Figure 27-16 Central Cluster Structure

Slotted Core Structure

Yet another design, shown in Figure 27-17, uses a somewhat over-sized core member of extruded plastic material that has slots or grooves around its outer edge. The core material may or may not incorporate a separate tension or strength member at its center.

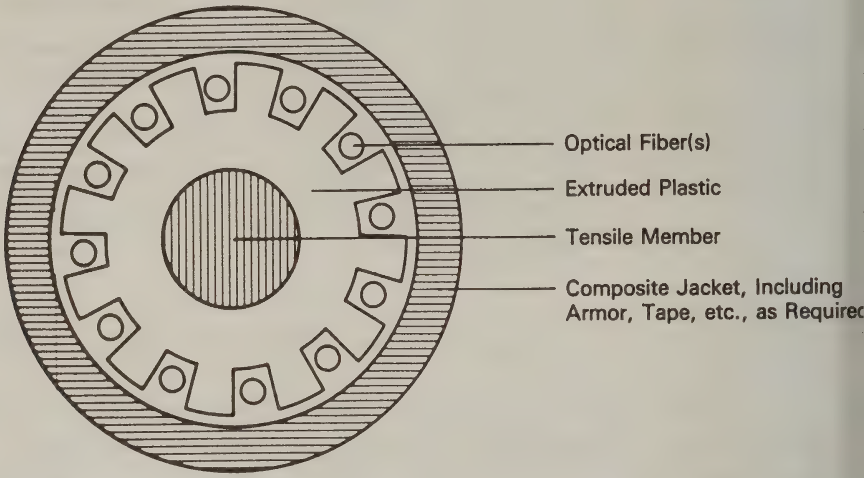


Figure 27-17 Slotted Core Structure

Called a *slotted core* structure, the fibers themselves are positioned within the outside grooves or slots, and there is sufficient room for extra fiber length. Since the fibers are loosely located, this type of cable may not use individual fiber buffer tubes at all.

Cable Design and Fiber Stress

In all of the preceding cable configurations, the fibers are *helicaly served* throughout the cable length, and flooding with elastic compound or gel is common practice to inhibit moisture. An examination of the different cable structures shows that, in varying degrees, all designs offer substantial isolation of fibers from mechanical and other stresses.

When, in the placement operation, cable is pulled into place or plowed under, a multitude of strains may be transferred to the cable structure, and eventually these strains may migrate to the cable core. This may introduce *cable elongation* or other distortion, but in good cable designs few of these stresses will be transferred directly to the optical fibers themselves.

The selection of thermally compatible materials, as in the case of the tight buffer tubes, and due attention to fiber buckling and the exclusion of moisture, produce fiber cables today that should certainly give many years of trouble free service.

Almost any of the cable structures, with the possible exception of the ribbon cables, can be procured with a wide range of fiber counts, which is the number of fibers within a cable.

Metallic Elements in Fiber Cables

One advantage of glass fibers as a transmission medium presents an entirely new option in physical transmission facility design. In either *multi-pair metallic* or *coaxial* cable systems, metallic continuity and thus electrical continuity was unavoidable, since metallic elements themselves were the transmission medium. Optical fibers, however, are made of glass and are *dielectric*, that is, they are of a non-conducting or insulating material. Thus it is possible to install a complete lightwave facility that introduces no metallic elements at all, and thus presents no electrical continuity along its length.

This would eliminate exposure to lightning damage, sheath currents, and possibly disruptive electrical disturbances. Such a facility would certainly be technically attractive, though it may not be entirely practical in some installations.

One advantage of a metallic element is structural strength, but with the multiplicity of materials available today, it certainly would appear that mechanical strength could be provided by using other materials.

Interconnection of Optical Fibers

There is a practical limitation to the lengths of optical fibers that can be drawn, and some restrictions on the cable lengths that can be readily placed in plant, although fiber cable reels holding 2 km lengths are not uncommon today, and longer lengths may be supplied on request. Of course we must also connect fibers to terminal equipments and other optical devices such as couplers or splitters. The interconnection of fibers is unavoidable.

Two clearly identified categories of interconnection are those where a *disconnect-reconnect* facility is required or desirable, and those that permit a more permanent or *hard* splice to be employed. In either category the questions of efficient transfer of energy, minimized optical reflections, and mechanical integrity must be resolved.

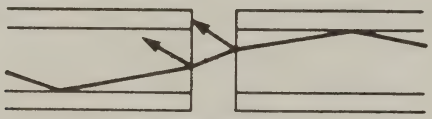
Sources of optical signal loss through any fiber connections are either *intrinsic* or *extrinsic* to the fiber. Intrinsic losses are due to the variations and mechanical characteristics of the two fibers joined, and cannot be compensated for by connector features or splicing quality. Fiber core size discrepancies and differences in numerical aperture between two fibers are examples of intrinsic connection loss. In a *connector type* fiber interconnection, intrinsic losses may be as great as 1 dB when fibers from two different manufacturing lots are joined, and may be worse if two different manufacturers are involved.

Disconnect-reconnect capability is available in a wide variety of *optical connectors*.

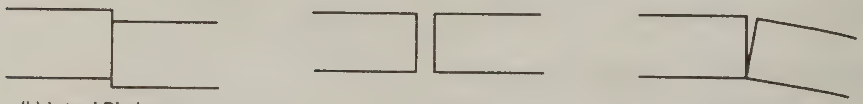
The dimensional control and stability of such units are quite critical if they are to function correctly after several disconnect-reconnect operations and due to the limitations of precise dimensional control, and the problems of fiber core realignment, connectors usually introduce significantly more transmission loss then hard splices.

For these reasons, optical connectors are generally limited to terminal locations.

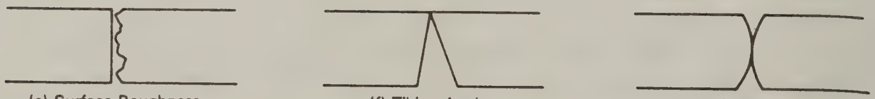
Extrinsic losses are not due to fiber composition or characteristics, and may be reduced by superior connector design or by a better splicing method. Some extrinsic problems are shown in Figure 27-18.



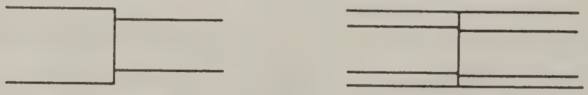
(a) Fresnel Reflections



(b) Lateral Displacement (c) End Separation (d) Axial Displacement



(e) Surface Roughness (f) Tilting Angle (g) Lensing



(h) Core Mismatch (i) Concentricity

Figure 27-18 Fiber Splicing Problems

Even cutting optical fibers requires care. A method of scratching or scribing a fiber with a *diamond scriber* can induce a clean break which is called *cleaving*, but in some splicing practices, polishing the end surfaces of the fibers is still required.

Fiber Splicing

Direct fiber-to-fiber splicing can be accomplished using mechanical devices or by *fusing* the glass fiber ends together. In either case, a fiber must be cleaned and all coatings (not cladding) must be completely removed. This may be done mechanically or chemically

Fusion splicing requires a fairly complicated splicing machine and some precision in positioning the fiber ends. Some fusion splicers include a high-power microscope which makes them difficult to operate in some work locations.
It is generally accepted that fusion splicing can produce individual splices with transmission losses on the order of hundreds of a decibel, and *mechanical splices* may be more conservatively rated at tenths of a decibel.

Sometimes reviewing the evolution of other techniques can be instructional, and the following may be a case in point.

Not too many years back, in multi-pair metallic cables for *toll service*, it was common practice to individually solder all pairs that had already been twisted together for connection, on the basis that this connection was superior for transmission purposes. This was awkward to do of course, and involved additional labor and costs, but this practice was widely adopted. It was later abandoned however, not primarily to reduce costs, but because over time, little evidence could be found to support the technical necessity for it.

A similar development can be found in microwave technology. In the earlier days of microwave, extraordinary effort was assumed necessary and was actually taken, in assembling antenna waveguide runs in the field. *Waveguide connectors* were proposed and sometimes used that incorporated tuning slugs so that waveguide runs could be fine tuned for minimum reflections. This required a sophisticated testing setup too, but it theoretically maximized waveguide performance. Today this is rarely used, and then only for the most sophisticated networks. The reason is that although each such installation was theoretically superior, it had limited beneficial impact on system performance, and did not justify the additional cost and complexity in many cases.

When technologies are embryonic, and lightwave inclusion into Cable Television systems might reasonably be so considered at this time, there may be some uncertainty as to how much sophistication is necessary or justifiable. The practicality of simpler fiber splicing techniques, glass sleeves with matching index gel for example, that can be done on the pole or in the field by lower level personnel, certainly has merit.

Of course we must consider transmission losses, and of course splice losses are significant. But splicing techniques such as fusion splicing, with its attendant cost and complexity which produces individual splice losses in hundredths of a decibel, may be somewhat excessive. Perhaps a mechanical splice that could be made many. many times with a minimum of field complexity, and consistently introduced losses on the order of 1 or 2 tenths of a decibel, would be quite practical and adequate.

Optical systems tend to be very conservatively designed today. The author has seen many installations that were so conservative that the receivers were *overdriven* with high-level optical input, and required optical attenuation to be subsequently inserted for proper system operation. And optical links in Cable Television systems, as in hybrid fiber/coax installations for example, are generally distinctly limited in fiber length, certainly they do not often require transmission links that are miles long, as optical links in Telephone trunk applications require. Perhaps the transmission loss of individual fiber splices is less significant in these cases. Perhaps hundredths of a dB of loss, difficult to even measure at best, are unnecessarily emphasized. Perhaps some emphasis might be given to the practicality of splicing operations, and their repeatability, with absolute transmission loss a secondary consideration.

Fiber Splice Testing

The emphasis on reducing splicing loss is accompanied by what may be considered excessive sophistication in testing splicing. If splice losses are actually established on the order of hundredths of a decibel per splice, then testing to that level of precision becomes a consideration of the splicing process. The practice of measuring the transmission loss of each individual fiber during splicing operations is widely accepted and generally applied today.

This may be done by temporarily coupling lightwave energy at a known level into the fiber that is about to be spliced. An optical detector coupled to a power meter, is temporarily connected in some manner to the fiber immediately past the splice itself. Light energy can be coupled loosely into and out of a fiber by wrapping the fiber around a test device mandrel. The losses of such in and out coupling are not significant, since they remain constant throughout the tests. The end result is a definitive measurement of the loss through the splice so effected, and of course, this can be minimized by manipulation before splicing, or by redoing the splice. Of course such tests, conducted on every fiber and every splice, is both costly and time consuming.

An alternative, assuming some reasonable repeatability in splicing technique and losses is available, would be to measure the transmission loss through sections of a system which included an intermediate, or several intermediate, fiber splicing locations. In Figure 27-19, we have applied a signal generator, a source of lightwave energy of course, to one end of fiber at one section terminal. If the transmission loss and length of each individual fiber on each side of the splicing location were known, and they must have been, then the power meter at the far end would indicate the cumulative transmission loss of these two fibers plus the loss of any splice made at the splicing location. If these losses correlate reasonably, splicing of all fibers could proceed without requiring any further testing at that splicing location at all.

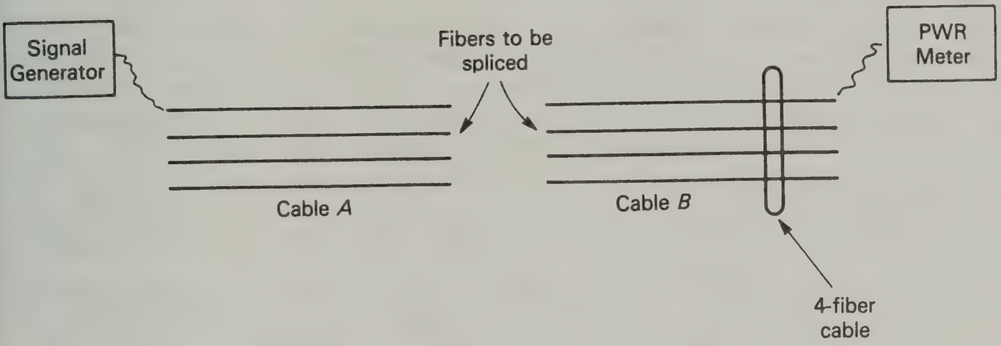

Signal Generator
Fibers to be spliced
PWR Meter
Cable *A*
Cable *B*
4-fiber cable

Figure 27-19 Measurement of Splice Loss

In actual installations, several interconnecting lengths of cable might be required, and there might be several splicing locations involved. In Figure 27-20 we show four cable sections identified as A, B, C, and D. This hypothetical project involves fiber splicing at three intermediate locations. The splices in each fiber are made between cable A and B, and between cable C and D, and these splices are purely mechanical operations with no individual splice loss tests at all. Of course we have initially assumed that the splicing technique is pretty predictable and repeatable.With a source of light applied to each fiber in turn at one system terminal, and with the intermediate splice already made, a power meter reading is taken at the location between cable B and C.

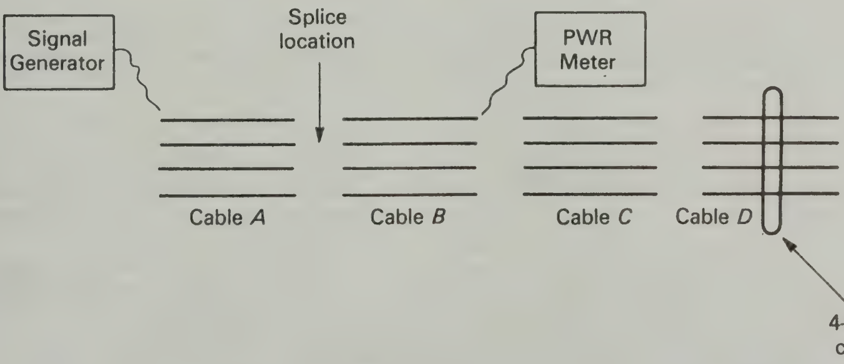

Signal Generator
Splice location
PWR Meter
Cable *A*
Cable *B*
Cable *C*
Cable *D*
4-fiber cable

Figure 27-20 Multiple Splice Testing

Then transmission losses can be calculated by fiber loss and length between the terminal and the power meter location. Losses above the fiber losses themselves can be assumed to be splicing losses introduced at the location between cable A and B.

The process is self-explanatory of course, but in this manner, splice loss testing could perhaps be reduced and simplified with acceptable risks. In effect, we might consider not measuring each individual fiber splice, depending on the repeatability of the splicing technique for acceptable losses, particularly if we had previously found only a small percentage of splice rejection to actually occur. We would rely on the signal level at the measured point to agree reasonably with the predicted transmission losses to that same point. If they did not, of course we would have to revisit the intermediate splicing location and take remedial action, but suppose they did agree with predictions.

Perhaps splicing methods and techniques are not yet sufficiently perfected to make this method entirely practical, but its advantages are very real and in low budget projects, might be quite attractive.

It should be noted that fiber splicing need not be sequential along the cable route at all. The object of any testing is to verify that acceptable transmission loss has been introduced by splicing into any individual fiber, and that each section of any fiber presents the end-to-end attenuation that it was specified and designed to introduce, or less. It is quite practical to conduct splicing operations in different sections of a system simultaneously, with the final splicing being the connection of two or more such sections, and of course, complete end-to-end loss tests. This is shown in Figure 27-21.

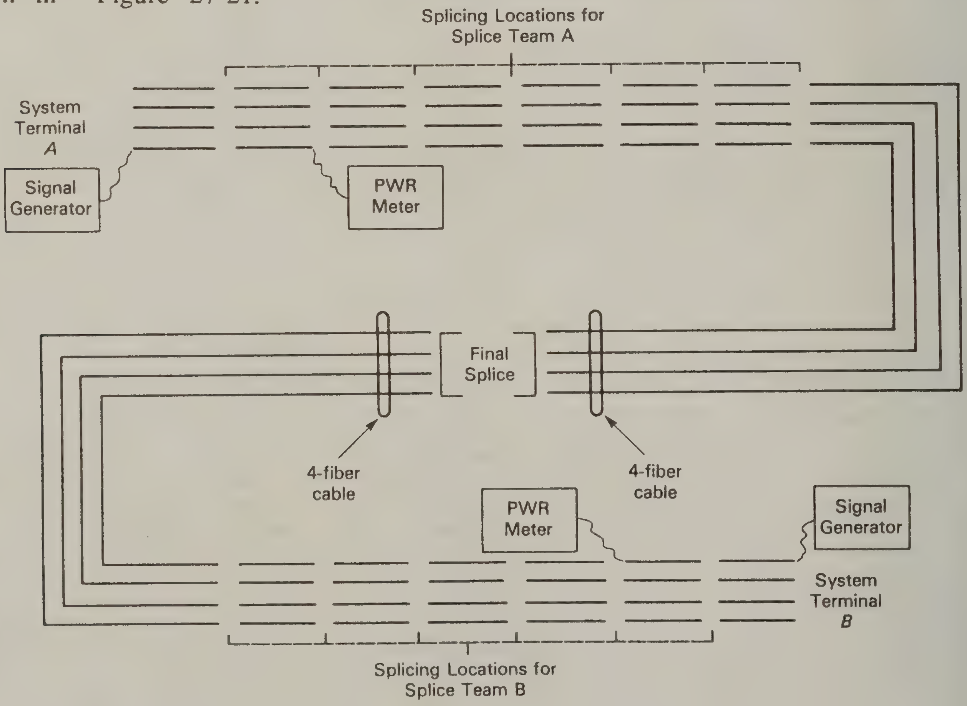

Splicing Locations for Splice Team A
System Terminal A
Signal Generator
PWR Meter
Final Splice
4-fiber cable
4-fiber cable
PWR Meter
Signal Generator
System Terminal B
Splicing Locations for Splice Team B

Figure 27-21 Multiple-Splicing Operations

Lightwave Plant Construction

Although construction methods for lightwave plant do not differ radically from more conventional metallic conductor installations, we need to be familiar with any different problems or requirements. Some of the differences are due to the basic nature of optical fiber cables. For the transmission capacity they present, fiber cables are much lighter, smaller, and somewhat more fragile than the metallic conductor structures.

The nature of the fibers themselves, both in the materials used in their fabrication and in their extremely small physical dimensions, makes fiber splicing a bit more difficult and uncertain. This is a persuasive argument to reduce, insofar as this is possible, the number of splices required.

In one early experiment that the author is familiar with, a construction program was designed and conducted to test several conventional construction techniques. The project involved aerial plant on new messenger strand, some aerial plant overlashed to existing telephone cables, and a significant amount of direct burial plant.
Construction craftsmen were exclusively from telephone construction departments, with no previous experience with optical cable placement or splicing at all.

The resultant plant produced was entirely satisfactory, even though none of these people had any previous experience with this alien technology. Not only did they place the plant using conventional methods, they had a respectable production output as well. This experience has been duplicated many times since then, of course, and there is no reason or evidence to indicate that exotic construction methods are required.

Although the earliest systems did not make any particular effort to reduce the number of fiber splices required, the apparent ease with which the fiber cables could be handled due to their small size and light weight, introduced a logical extension of reasoning to address this possibility. When it became evident that fiber cables could be fabricated and supplied in greater lengths, the basic construction methods were reviewed to see if these greater lengths could be utilized, to reduce the number of fiber splices required.

The factor of greatest concern was the relatively low tensile strength that most fiber optic cables present. If long lengths were to be employed, then cable pulls would have to be restricted in length or other construction techniques developed and employed.

Fiber Splicing

Although fiber splicing is a demanding and sophisticated operation, new developments in splicing and connectors have been developed and found to be adequately satisfactory.

The primary objection to several splices in any fiber are no longer quite as convincing, and undue emphasis on this point may be counter-productive. Obsession with mechanical detail has been evidenced in other technical evolutions, of course. The author recalls an instance many years back in the construction of some coaxial cable plant.

The customer's engineering department was irrevocably convinced that the use of coaxial cable connectors was not merely undesirable, but would significantly degrade the transmission performance of such plant as well. They insisted that all coaxial cable runs between trunk amplifier locations must be continuous lengths of coaxial cable, and no intermediate cable connectors were allowed.

Since the amplifier locations were fixed by normal considerations such as cable losses and bandwidth provisions, this entailed some long intermediate cable runs. The construction crews were obliged, in some cases, to place these runs with 2 or 3 ninety degree corners as well as excessively long cable pulls. In some cases, despite extra care in placement, the coaxial cable itself was deformed and flattened as it went around these corners and, in these cases, more serious transmission difficulty was encountered and unnecessary extra construction costs were involved. The obsession with cable connectors alone created most of this.

The point, of course, is that sound judgement and due consideration must also factor into any decisions on fiber splicing as well as the purely technical effects. Fibers can be spliced with acceptable introduced losses, and this can and does result in reduced placement costs sometimes. Of course when fibers were employed in much longer runs, as in telephone trunking services, these splicing losses were a more serious consideration than in shorter Cable Television distribution systems.

Sometimes, in Cable Television systems, a fiber or two must be terminated periodically to serve a "node" in hybrid fiber/coax applications. The fiber count of the cable may not change, but we are obliged to terminate a fiber or two for service at that point, with the remaining fibers passing on to subsequent "node" locations. In such cases, that physical location requires a cable appearance anyway, and housings, etc. are already available. Using such locations for fiber splicing may shorten and simplify subsequent fiber cable runs.

Fiber splicing is a viable option and tool in the design and construction of practical, technically satisfactory transmission systems, and it should not be discarded as an option casually.

Underground Cable Placement

We define underground cable placement as cable that is placed within independent ducts or pipes beneath the surface. This is opposed to buried plant where the cable is placed underground as a single plowing or trenching operation without protective pipes or ducts.

In underground conduit systems, manhole spacing reflects both the length of metallic conductor cables that can be handled, and the strength that such cables must have agaimst damage from the pulling operation. The first efforts at longer fiber cable pulls in such systems was for personnel to manually assist the cable pull at intermediate manhole locations. This was reasonably successful but the pulling tension that was actually being transferred to the cable was difficult to determine or constantly sustain with precision.

One approach was to make a series of shorter pulls possible without using a number of shorter cable lengths, as seen in Figure 27-22.

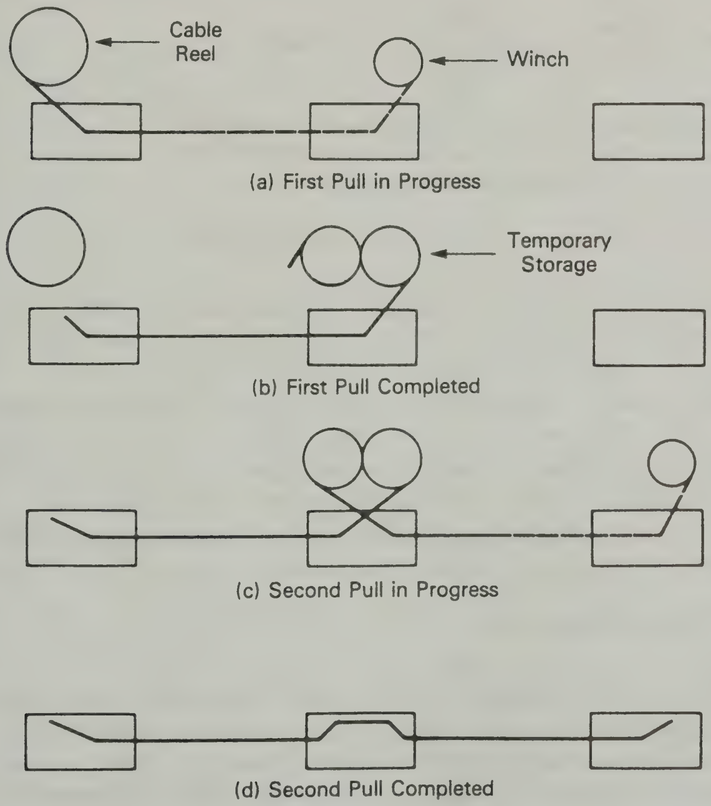
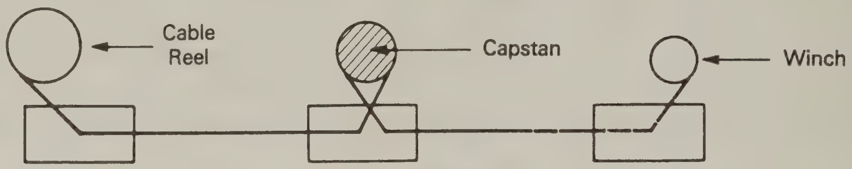

Cable Reel
Winch
(a) First Pull in Progress
Temporary Storage
(b) First Pull Completed
(c) Second Pull in Progress
(d) Second Pull Completed

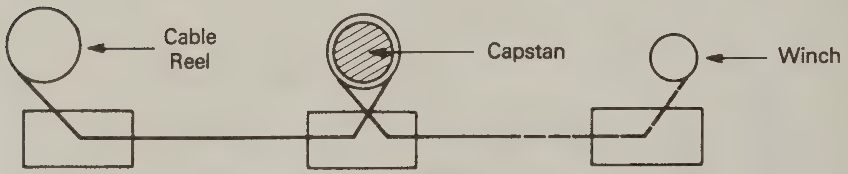
Figure 27-22 Temporary Excess Cable Storage

Here the entire length of cable is pulled off the reel and through the first conduit section. This necessitates storing the excess cable in some way until the second cable pull can be made. A technique of coiling the excess cable in a figure eight on the ground was developed. After completing the first conduit pull, the pulling winch was moved to the third location as in the figure, and a second pull was made, pulling the stored cable out of its temporary figure-eight configuration. In this manner, no single conduit pull was excessively long or imparted undue tensile stress to the cable.

A refinement on this technique used a power capstan at intermediate pull locations as shown in Figure 27-23.



(a) Pulling Tension Applied



(b) Pulling Tension Absent

Figure 27-23 Power-Assisted Pull

With several turns of cable around such a capstan, which must have an acceptable bend radius of course, when tension is taken up on the cable past the capstan location, the cable is tightened around the capstan drum. The capstan then automatically imparts pulling power to the cable between the capstan and the reel location. In effect, two or more short pulls can be made as one work sequence, and since the capstan removes pulling power when the original pull tension is removed, each capstan applies pulling power only when necessary.

In underground placement operations, cable lubricants are usually applied to further reduce the tension load on the optical cable.

Direct Burial Cable Placement

As used here, direct burial means plowing the cable underground in a single placement work operation as opposed to placing cable into open trenches or pulling cables into an existing conduit system. Direct burial of cable is by no means a new construction technique and much of the same basic equipment and techniques used in plowing multi-pair or coaxial cables are directly applicable to fiber cables also.

The placement plow shoe may be larger in diameter to assure meeting radial bend requirements of fiber, and some equipment is equipped with tension measuring to further assure gentle cable handling.

Several alternatives for cable plowing exist. Sometimes an all-dielectric cable is first placed inside a protective, semi-rigid, plastic material conduit before plowing operations begin. Then this entire assembly, cable plus conduit, as a single, integrated item, was plowed. Sometimes the plastic conduit alone is plowed under, and the fiber cable is pulled into that conduit in a separate, later operation. Yet another technique uses a "split" plastic conduit, which has a longitudinal opening or slit along its entire length. The conduit is plowed continuously, and the fiber cable is inserted, through the slit, into the plastic conduit as the plowing operation proceeds.

Where plowing operations cannot be continuous, as at a river crossing perhaps, either a splice location must be established, or some form of temporarily storing excess cable length, such as the figure eight arrangement discussed earlier, must be employed.

Aerial Cable Placement

There are almost no differences in aerially placing metallic paired cables, coaxial cables, or fiber cables. Optical cables can, like each of the other two types, be supplied in a self-supporting structure, or they may be *lashed*, using conventional lashing equipment and techniques, to new messenger or strand. Because of their smaller size and relatively light weight, fiber cables may also be *overlashed* onto existing strand that already supports multi-pair or coaxial cables.

Fiber splice housings and terminal device housings already accommodate some surplus or extra fibers within them, so no external provision for extra fiber cable need be provided.

Electrical Bonding and Grounding

When optical cables include a metallic element, sometimes for strength or moisture protection for example, the question of what to do with the metallic element at splice or terminal locations arises. Should they be bonded through the location, establishing metallic continuity end-to-end throughout the system? Should they be grounded also? Let's address them separately.

Bonding describes the electrical interconnection of different devices, sections of a system, or even two entirely different systems or plants. It is primarily intended to protect personnel and plant from differences of electrical potential that might exist between two devices or plants. Thus Telephone and Cable Television strand is bonded together, and to power line grounds frequently. When locally bonded together, the two are maintained at the same electrical potential, thus protecting personnel.

Grounding is designed to disperse high voltages or currents from the plant by providing a low-resistance path to groun

Bonding and grounding together are usually required in joint use plant, for example, where telephone, cable television, and power plant are all on the same poles.

When conventional multi-pair or coaxial cables are involved, both bonding and grounding are not only good practice, it is usually required. The fact that the transmission medium in an optical fiber cable is dielectric, that is, it does not conduct electricity, is irrelevant. The inclusion of a metallic element in the cable structure requires the same protective measures that any other cable plant requires. Thus the same practices, regarding bonding and grounding, should be followed.

Note that if all-dielectric cable is involved, no bonding or grounding is mandated at all. Even in self-supporting cable structures, if no metallic element at all is included, which means that the strength or supporting member must ne non-metallic, then no particular bonding or grounding practices must be observed. Such cables are actually available.

Summary

Almost all conventional plant construction techniques are suitable for optical fiber cables also.

The inherent small size, light weight, and flexibility of fiber cables makes longer continuous lengths of cable possible.

There are no transmission considerations that inhibit the use of completely dielectric fiber cables, and such cables are relatively immune to lightning, electromagnetic induction or noise, and electromagnetic pulses (EMP).

Fiber ends can be joined by fusing them together or by using mechanical splices or connectors.

There are no insurmountable problems in constructing lightwave plant, and no extraordinary costs are involved in such construction. Indeed, some techniques are possible that could reduce the cost of lightwave plant construction, overlashing onto existing multi-pair or coaxial plant, for example.

If mental reservations are present because lightwave transmission and optical fibers appear to be an untried or embryonic technology, they certainly have been constructed and operated in sufficient quantities, and methods, hardware, and production improvements have been adequately demonstrated, to overcome any such reservations. This is a mature and available technology.

Chapter 28

Hybrid Fiber/Coaxial Systems

This text has developed, in some depth, the design and engineering of RF broadband coaxial cable systems as used in the Cable Television industry. We have also presented some introduction and background on lightwave transmissions on optical fibers. It remains for us to marry these two technologies gracefully in what we have come to call hybrid transmission systems. This term refers to transmission systems that use both optical fibers and coaxial cables in tandem as a single, discrete transmission facility for Cable Television distribution, and perhaps other services as well.

We might usefully review the basic characteristics and capabilities of both of these first.

RF Broadband Coaxial Cable Systems

In these applications, coaxial cable is used throughout, and the signals (television signals predominately) are all carried in an analog mode separated by frequency division multiplexing techniques. Bandwidths on the order of 800 mHz are practical, and 60, 70, or even more individual television channels may be carried on such systems.

The transmission losses are such that fairly frequent reamplification of signals is obligatory, and this introduces a significant number of RF broadband amplifiers in tandem, or serially connected. Cascades of as many as 30 or 40 amplifiers are not uncommon in coaxial cable systems. Of course, since these are analog devices, the noise and intermodulation distortion of each such amplifier is cumulative in the end of system transmission performance, and since each such unit requires operating power, a multiplicity of powering locations is involved.

The cascade of many such active amplifiers, and their powering requirements, introduces significant exposure to failure or service interruption.

As we expand the transmission bandwidth of such systems, and we must if we are to expand the number of television signals we transport and offer, the practicality of multiple amplifier cascades becomes questionable.

The economics of such plant is related to the transmission levels and amplifier gain we employ of course, and any increases here, although they may improve the efficiency or economics, inevitably introduce even more distortion and noise.

And the basic technology, broadband coaxial cable, is subject to electromagnetic interference from signal ingress and egress, AC hum, etc. The gross discrepancies in transmission losses from lower frequencies to higher, the susceptibility to temperature changes, the equalization necessary, all tend to complicate the long term operation of such systems, and lead to sophisticated and complex testing and maintenance procedures.

One might think we have reached the pinnacle level of development in this technology, that there simply isn't much room for system improvement or the future development modern systems seem to call for. Nevertheless, this is a mature technology and tapping such systems for service to a multiplicity of randomly located subscriber premises is practical and reasonably economical today. Cable Television service, using this in-place technology, has been and is economically attractive.

Lightwave Transmission Systems

The development of lightwave links themselves, and the prediction and realization of acceptable transmission quality in those links, is a welcome development in this dilemma. It presents a rather natural extension of transmission bandwidth, which was somewhat limited with coaxial designs. It eliminates the multiplicity of cascaded amplifiers, replacing them instead with only two active devices, the lightwave transmitter and receiver. It requires no intermediate reamplification for the transmission distances normally encountered in many Cable Television applications, and does away with powering any such intermediate units as well.

It employs optical fibers and operating frequencies that are relatively impervious to electromagnetic interference, and that require little signal equalization or self-regulation to offset ambient temperature changes. In short, lightwave links need little long term attention or sophistication to maintain acceptable levels of transmission quality.

But lightwave links do suffer shortcomings. The transmission levels are rather low, and they do not lend themselves well to the multiplicity of subscriber taps that are a necessary function of Cable Television distribution. And if we attempt to extend lightwave signals into each subscriber premises, then we are obliged, since the end device to be served is the subscriber owned television set, to transition from lightwaves to RF signals at each and every such station. This distributes significant cost and sophistication to the lowest common denominator in such systems, the many, many subscriber terminals themselves.

Hybrid Transmission Systems

If we blend both these technologies gracefully, we might combine the advantages of each, or at least minimize the disadvantages, in a composite transmission system that employs both optical fibers and coaxial cables.

We have come to call such systems hybrids. The lightwave link strong point is eliminating many intermediate RF amplifiers in reaching deep into the service area, thus improving not only transmission quality, but the service reliability as well. We will adopt and apply this in hybrid designs.

The coaxial cable plant offers significant economies and efficiency in service tapping, particularly in serving a large number of randomly located service points. We will adopt and apply this in hybrid designs.

We'll subdivide or sectionalize a Cable Television service area into a number of smaller. stand alone, transmission systems. Each will employ a lightwave link using optical fiber for arterial transmission for significant distances, and each will transition to RF broadband coaxial plant, of limited length, to accommodate direct subscriber tapping for service. We will limit the coaxial extensions to two or three amplifiers in cascade, and thus the problems of temperature change, and signal equalization, will be drastically simplified.

Since we are obliged to provide operating power for each lightwave receiver anyway, we will simply expand this powering capability to include all coaxial amplifiers served in tandem from that lightwave receiver, thus sectionalizing and improving the reliability of the transmission system itself. The term node has become generally employed to denote the sections of an area that a single lightwave receiver may serve directly. In Figure 28-1 we show a single fiber serving a single node in this manner.

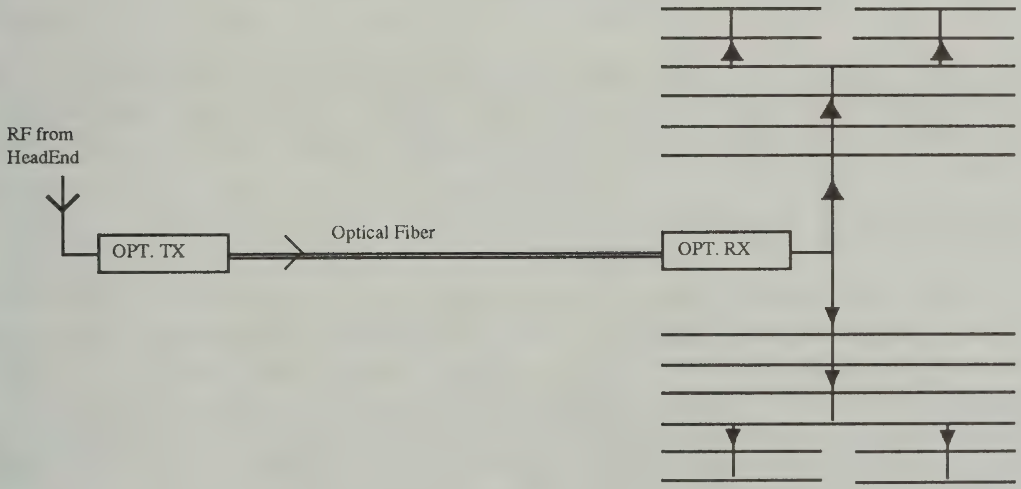


Figure 28-1 A Hybrid System Node

To accommodate this architecture, we are obliged to extend all of the signals out into the service area on a number of paralleling optical fibers of course, each fiber directly serving one or two nodes, and each such node extended with a limited cascade of coaxial amplifiers. Figure 28-2 shows two nodes of service in a hybrid system.

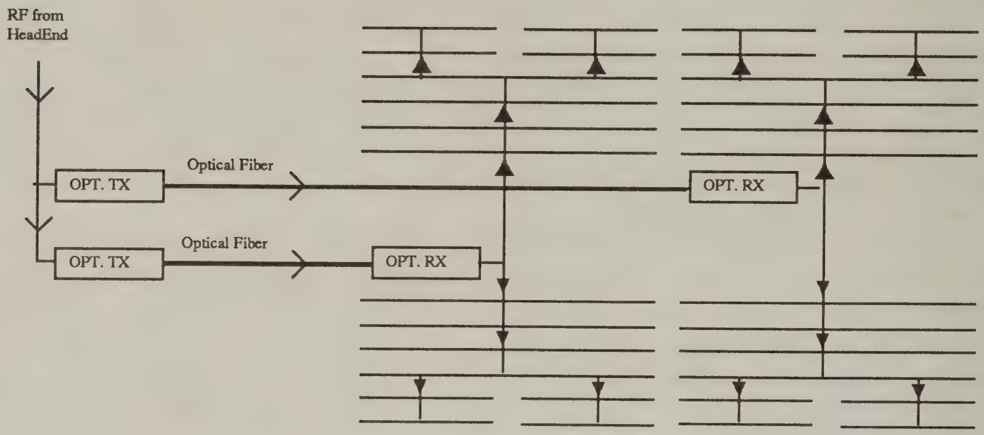


Figure 28-2 Two Nodes in a Hybrid System

Each parallel fiber will require it's own lightwave transmitter of course, but each independent sub-system of the hybrid type will be self-sufficient and technically independent of any other. That sounds pretty easy, but it introduces some unique questions of its own.

How Large is a Node ?

One must assume that any and all plant will be required to operate in a two way or bi-directional mode, and must accommodate transmissions both to and from each subscribers premises. The downstream television transmissions, that is, from the system Head End to each subscriber, are all common to all subscriber stations and thus the size or area served by a single node would be independent of this factor. Other services, perhaps some of them yet to be developed, will be the major determining factor in establishing node size.

To date, the size of a particular node seems to have been rather arbitrarily arrived at. There are those in the industry that limit node size to 500 subscriber stations, others appear to opt for 1,000 stations, and these are both defensible quantities arrived at, perhaps, somewhat intuitively.

The nature of these other services may, or may not, be directly associated with Cable Television service itself. In the one case, it might be an interrogatory type of downstream transmission to each subscriber station in turn, using digital addresses on a single transmitted carrier to all stations.

Such inquiries to stations might be to establish the current status of service for that station, or to permit changes in service status or temporary authorization of some services. Pay-per-View services come to mind in this respect, and the cable operator might wish to periodically reach, and enable, any station served to alter its own condition with an individual response.

Some of these services may not be directly associated with Cable Television, indeed they may even be offered by other corporate entities using the transmission system. Such services as power or water metering, and intrusion or fire alarms come to mind.

In either of the above cases, each station would be individually addressed in turn, using a common signal, and each would be individually, in turn, permitted to transmit data back to the Head End, again using a common signal. This is a form of time sharing, interrogatory type of operation, and perhaps hundreds of stations can be digitally interrogated in a matter of minutes or less. In such a service, all stations need not respond at the same time, and the delays in transmission in both directions, being somewhat nominal, might be quite acceptable.

Interrogatory time sharing services of this type are in common usage on conventional all-coax systems today of course, and it should be noted that if the composite transmission system is operating on a broadband analog basis, such operation is equally practical on hybrid fiber/coaxial plant. The size of a node, in these cases, is dictated by the number of stations that can be practically interrogated and responding in a reasonable period of time.

One finds it difficult to disagree with either the 500 or 1,000 station node size in these applications. It appears that the size of a node will certainly reflect the multiplexing scheme that will evolve to accommodate other services, and as such services and the methodology for establishing them is as yet uncertain, then some arbitrary size must be selected. We are disposed to adopt 800 stations as the size, which should leave some room for growth or additional stations at a later date in most applications.

New Two Way Services

There are other subscriber services that are possible of course, and perhaps some of these are both more technically demanding, and more embryonic as well. Nevertheless, we are obliged to consider these, even if they are somewhat unresolved or finalized as yet. One classic example might be plain old Telephone service itself.

The provision of subscriber Telephone service, commonly called Exchange service between the individual subscribers premises and the first Telephone switch in the National switched network, is a much more severe requirement. Telephone service requires the temporary connection, on demand, of any two individual stations in a switched network of thousands of such stations, millions actually.

Beyond this, the switched connection is required to be a full talk, or full time connection for the period of the Telephone connection itself.

In effect, either or both subscribers can hear either or both subscribers talk, even at the same time. This is radically different from conventional Cable Television service, where all signals are presented to all points of service, all of the time.

Although this text is directed at Cable Television alone, and we do not propose to explore this development in greater depth, we are proposing a transmission system of a local nature that is two way capable, and we cannot completely ignore this consideration. How such a service might be universally adapted and incorporated may have a very real influence on the size of service nodes in hybrid systems, and we are obliged to design, construct, and operate such systems today.

Since such a development is not presently wide spread, or even generally accepted technically, or clearly defined as yet, it does not qualify as instructional text material. It is better handled in the form of a study or hypothetical development at this time, and the author has generated, and does offer, just such a study for Integrating Exchange Telephone and Cable Television Services on a single, common transmission facility. This study program is available directly from the author or through the services of the Society of Cable Television Engineers.

In any broadband facility, and it is our intention to operate hybrid broadband systems in this mode, we are providing substantial spectrum for use to and from each and every point of service. Regardless of the type of individual modulation employed for such circuits, or the scheme used for multiplexing, a number of individual Telephone circuits must be accommodated on such systems. It is practical to provide such circuits in a repeatable manner, that is, a limited number of practical circuits will undoubtedly be developed, and would simply be repeated on different fibers serving different nodes in any large system. Our basic architecture, which provides a number of limited service point nodes on a number of paralleling fibers, lends itself well to this end.

As a point of departure, and without further definition, we will settle on a standard node size on the order of 800 subscriber stations or so, but this number is arbitrary and just as we are not empowered or inclined to dictate system performance specifications, neither will we mandate the finite size of a node in any hybrid system.

Configuring Hybrid Systems

Then the first step in any hybrid system development is to clearly define the service area of a node, each node in turn served by its own optical fiber. But this is also subject to some modifications. Suppose we do decide to serve 800 stations with a single mode, but the geography of the composite service area or town does not offer comfortable increments of this size? Perhaps rivers or peninsulas are involved here.

We can, with existing lightwave hardware and technology, serve two nodes by optically splitting the fiber itself.

In this case, we would still require two lightwave receivers of course, but we could employ only one lightwave transmitter on that common fiber. In this manner, downstream spectrum would be made available to all points which were served by that fiber, regardless of the fiber split itself. We show just such a configuration, on a one way transmission basis, as Figure 28-3.

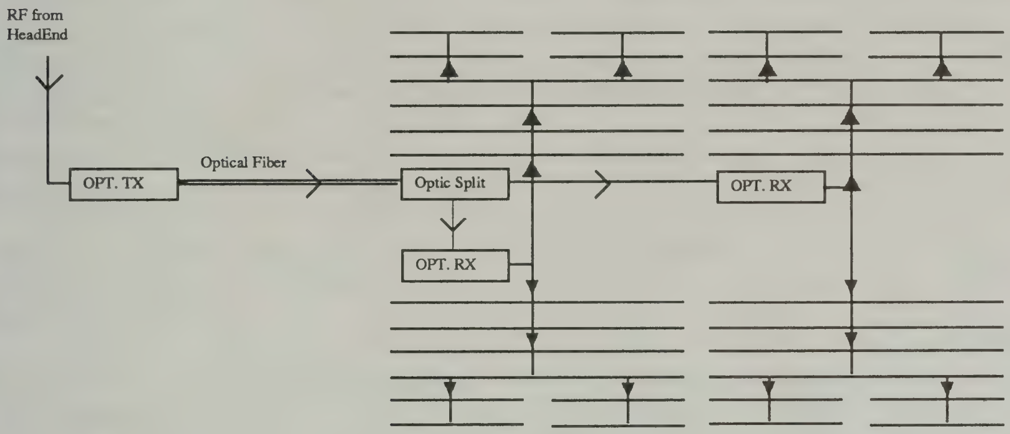


Figure 28-3 One Node Using Splitting

The common connection of the spectrum in Figure 28-3 at both the Head End and at each subscriber terminal is quite straight forward and should introduce no complexities at all.

Two Way Operation

We cannot ignore, nor should we, two way operations on hybrid systems. The coaxial portion of the system, and its two way operation, has been quite adequately covered in the earlier sections of this text. It is necessary, however, to discuss two way operation in hybrid applications, and in Figure 28-4 we show a fiber link alone as equipped for two way transmissions. Note that we show both the use of a single fiber, using WDM techniques, and the use of a separate fiber for the return transmission path.

At the point of interface with the coaxial cable portion of the system, the two separate spectrums, downstream and upstream, are naturally divided by the two way filters in the RF amplifiers themselves, and no special discussion of this capability is necessary. If a separate fiber is involved in the return transmissions, the upstream spectrum is extended to this fiber by its own lightwave transmitter.

If a bi-directional fiber is used for the return path, the return spectrum is applied to a lightwave transmitter, at a different lightwave frequency of course, and its output is extended to the proper port of the WDM device, as shown in both sections of Figure 28-4.

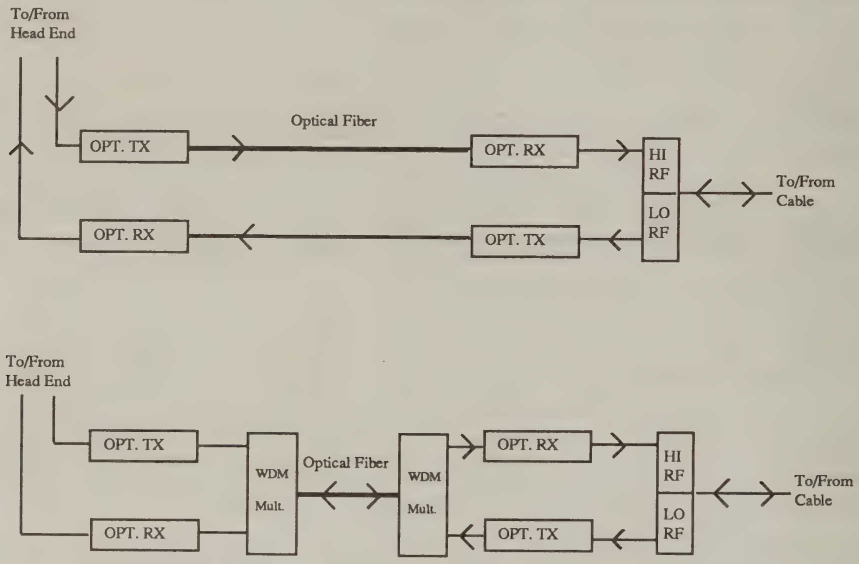

To/From Head End
OPT. TX
Optical Fiber
OPT. RX
HI RF
LO RF
To/From Cable
OPT. RX
OPT. TX
To/From Head End
OPT. TX
WDM Mult.
Optical Fiber
WDM Mult.
OPT. RX
HI RF
LO RF
To/From Cable
OPT. RX
OPT. TX

Figure 28-4 Two Way Fiber Options

The decision as to whether or not a single fiber is used for both directions of transmission is more a business or economic judgement, and might reflect the size or geography of a particular application. Both techniques are technically sound and both options are available.

Transmission Engineering

A hybrid system, like any transmission system, can be logically divided into component sections, and the transmission performance of any section can be individually determined. We learned all about this earlier in this text when, in conventional coaxial trunk/feeder systems, we developed the performance of the trunk plant and the feeder plant individually. Composite system transmission performance was simply a matter of combining these two performances.

This same methodology applied, you will recall, when we considered the Head End performance, or the inclusion of a microwave transportation system. Overall transmission performance simply required combining individual section or element performances.

This is essentially true of hybrid systems as well, but this process can be complicated if we are obliged to consider the composite system as carrying both analog and digital signals in some mixture of services. There are no such applications wide spread as yet, but future requirements will undoubtedly develop. Even in such cases, however, some statistical loading factors can be developed for the digital carriers and some translation to common performance specifications is possible. If common terminologies are developed, the process of combining performance can proceed.

In this text and at this time, we are concerned with signals or services that relate directly to conventional Cable Television service, and this service is, at present at least, primarily analog in nature utilizing Frequency Division Multiplexing, just as conventional coaxial cable systems presently do. Since we can clearly define the elements of a hybrid transmission system, that is, the optical fiber section and the coaxial cable section, then we can readily determine the performance of each element.

We must define and state the transmission performance of both distinct elements in compatible terms and units. Then the development of an overall, end-to-end system performance is rational and follows the earlier methodologies for combining element performances.

Since our objective is the practical development of hybrid system performance by technicians and engineers working in the field today, that is the process that we will present and follow here, and the fact that these are two distinctly different technologies of transmission will be irrelevant. We can apply much of our previously gained understanding of coaxial broadband transmission techniques directly.

Transmission System Development

In coaxial cable systems, the number of RF amplifiers employed influenced the transmission levels at each amplifier, and determined the end-of-system performance. In effect, since the distance to be covered changed with each application, we ended up with customized engineering for each such section or we ended up with better performance in parts of a system. All sections met system specifications of course, but shorter sections performed better. Since all subscribers received at or above specified performance quality, this was quite acceptable.

Note that we are not talking about RF signal levels as delivered to the subscribers sets in this case, of course these levels were all about the same or at least all within some reasonable "window." But all subscribers did not receive the same quality of picture, that is, they did not all receive signals with the same or nearly the same C/N Ratio or Intermodulation Distortion.

But with lightwave links, the active and contributing elements are distinctly limited for all subscribers, to one lightwave transmitter, one lightwave receiver, and 2 or 3 or 4 RF amplifiers in cascade. Consequently all subscribers, regardless of distance from the Head End, are all fed signals of the same "quality," or very nearly so. In effect, all lightwave links produce the same quality of signal regardless of their length, and all node coaxial extensions start, or are fed, with the same quality as well.

Since there are no intermediate amplifiers, only a lightwave transmitter and receiver is involved and contributing in all lightwave links, the transmission performance of any link may have only a limited relationship to the physical length of that link. Then the only consideration is the manufacturer's specified performance of the lightwave transmitter and receiver when carrying the specified number of signals.

This is only true if we observe and comply with the transmitter lightwave output as specified, and the receiver lightwave input as specified. The lightwave receivers themselves have some dynamic range in that they will accept some variations in input signal level, and still deliver essentially the same transmission performance.

In a very real sense, transmission engineering is much simplified and less uncertain, and so is maintaining the link performance over an extended period.

All we have to do is consider the system elements that exist between the lightwave transmitter and receiver, and make certain that these do not impose a lightwave input signal to the receiver that is significantly below the manufacturer's specified level. If we do this, and the lightwave transmitter output is as stated, then so is the transmission performance of the link itself, and the manufacturer has already told us what that would be.

The factors to be considered then are the lightwave transmission losses inserted or required between the transmitter and receiver, and these are all rather easily developed. They consist entirely of fiber losses, optical splitter or coupler losses, and placement and splicing losses. In the matter of splicing losses, we may have to make some allowance for splices that might be required at a later date in repairs of massive fiber damage or disruption, of course.

Variations on Transmission System Development

Lightwave transmitters do present different transmission performance under different loadings of course, and we will find some situations where the initial design of a link is under utilized. We may anticipate a link to carry say 70 channels at some future time, and we select equipment and design the link spacing to accommodate this subsequent capacity, but initially it may be only loaded with say 50 channels.

One might reduce the transmitter output by internal adjustment somehow, and perhaps improve the performance somewhat under this lighter, initial load. Subsequent transmitter adjustments might be necessary as transmitter loading is increased later. This is not only possible, some lightwave equipments available on the market today actually do provide some inherent adjustment.

In such an instance, the link engineering and initial adjustment is complicated a bit and somewhat customized, but the initial performance might actually be improved. One finds it difficult to argue or disagree with any possible improvement, but it also introduces an adjustment into the equipment, and that in turn introduces the potential for subsequent mis-adjustment by field personnel. Such mis-adjustment might be inadvertent through a lack of familiarity or might mask some other problem by improper corrective action by well intentioned personnel.

Although such adjustments may be possible, we ought to carefully consider the degree of initial service improvement that might be possible against the less obvious but very real advantages of standardized link engineering, unchanging universal transmission levels to verify and maintain, and the risks of incorrect or unnecessary readjustments over time.

Coaxial Cable System Extensions

At lightwave receiver locations, where coaxial cable nodes are fed, the transition from lightwave signals to RF signals is equivalent to an AML microwave receiver action, that is, the transition is Heterodyne in concept and does not require demodulation to video and audio, and remodulation of RF carriers. This eliminates all possibilities of under or over modulation at these locations of course, and such locations are quite easy to maintain and service, even to monitor long term.

But the coaxial extensions will be, to some extent at least, dictated by the geographics of the service area, as well as the subscriber count to be served by a single node. Such considerations as rivers or lakes may come into play. Certainly it is rather straight forward to determine the transmission performance of any cascade of RF amplifiers, and we have discussed this at length earlier. If such units include AGC or other automatic regulation is a bit academic here also.

If all lightwave links in a hybrid system produce the same quality of signal regardless of length, we would greatly simplifiy hybrid systems if the coaxial cable extensions all did the same. If all coax extensions are say 4 amplifiers deep, and all are operated at the same input and output levels, then the extensions would all have the same performance.

Hybrid system perfromance would be easy in such a case. All lightwave links would produce the same quality signal, all coax extensions would produce the same signal quality, and the combination of both performances would mean that all nodes would produce the same signal quality at their most distant amplifier output.

This depends on all coaxial extensions having the same number of RF amplifiers in cascade. How were “feeder” or “line extender” amplifier cascades established, in effect establishing a “standard” feeder cascade of two, in the past?

Since trunk amplifiers cascades were uncertain and depended on the actual distance out to the last feeder, the “quality” of signals as to noise and distortion was somewhat uncertain at trunk ends also. Experience and engineering determined what feeder extensions could reasonably contribute here, and the state-of-the-art dictated 2 line extenders as the standard feeder cascade. The maintenance of all systems was simplified as well, if all or most feeders were the same in amplifier cascades. All operated at the same input and output levels, didn’t they?

We handled unusual feeder requirements, that is 3 or 4 units required, as exceptions to the rule. We have some previous knowledge or operational experience that may be useful here. We generally applied the concept of cascading only two such feeder amplifiers as a rule, to limit feeder contributions to distortion, and took the simple expedient of reducing the usable gain, and thus the output levels, of such units when it was necessary or expedient to extend the feeder to three such amplifiers.

This did introduce system "non-standard" signal levels in sections perhaps, and this does complicate system long term maintenance a bit, but it was one practical approach that was widely applied. We could simply adopt this same time tested technique in the case of hybrid coax extensions.

In hybrid systems, since the "quality" of the signals fed to every coaxial extension is quite high as compared to the "quality" fed to a feeder cable at the end of say 30 trunk amplifiers or so, we have more freedom of choice. We probably could accept the noise or distortion contribution of 3 or 4 RF amplifiers in cascade, and simply reduce outputs only on unusual extension lengths, as we did in all-coax systems.

It is not our desire or intention to mandate the actual cascades introduced in hybrid systems. System operators and their engineering capabilities have done this to date, and there are some companies that opt for longer cascades than others. We take no exception to this, and there may not be a single best answer which could be applied. Perhaps, in some cases, the RF amplifier cascade will be established by the "node size" that is provided, and this also varies with different operators.

We do suggest that a "standard" cascade has merit, simplifies hybrid designs, and greatly simplifies long term maintenance however. Remember that the end-of-system performance will still be the combination of the lightwave link performance, and that of the RF amplifier cascade as well.

If we confine those adjustments required by unusual demographics to one element of the system alone, in this case to the coaxial extension alone, then the optical portions or lightwave links may be more easily and uniformly addressed.

Incidently, because there are fewer contributing elements in a hybrid system, that is, the lightwave link and only 3 or 4 RF amplifiers, it allows us to employ with some economic advantage RF amplifiers of slightly higher gain. And, because we have increased the transmission bandwidth somewhat, and we expect to tap all the coaxial extensions for subscriber service, we may well find equalization of signal levels more frequently used in the coaxial sections of hybrid systems. Passive, in-line equalizers, covered on Page 167 of this text, would help equalize signal levels at service drops and may well be used more often than we have seen, or was required, in conventional all coaxial, limited bandwidth systems.

The process of tap selection to accommodate changing signal levels along a coaxial cable run, while feeding all service drops the same signal levels, or nearly so, is unchanged in either all-coaxial or hybrid systems, of course.

Lightwave Link Performance Development

Having arbitrarily established the size of a hybrid node in terms of subscriber stations served, we can easily transpose this into the physical plant required to service such a node. This translation will present the transmission distances or plant lengths involved in terms of link loss.

Since the transmission performance of any link is already established by the manufacturer's specified performance of a lightwave transmitter and receiver working together under specific conditions of loading, then all that is required of us is that we do not exceed the manufacturer's mandated transmitter output or receiver input, both at lightwave frequencies.

How can we accommodate the natural variations in distance and plant length? If we can of course, we can ensure transmission performance through the link at a predictable and acceptable level.

We first determine, given the distances, the link end-to-end loss at the proposed lightwave frequency. Since fiber splices individually introduce such loss, we are obliged to estimate conservatively, the number of splices that will be required. We may, and prudently should, include some figure for the losses introduced by any future maintenance splicing that may be required.

If we know the lightwave energy input to the interconnecting fiber, and you remember that was determined by the transmitter manufacturer's specifications, then we need only add all losses together, subtract this figure from the transmitter output, and establish the lightwave energy at the receiver input. If it is at the manufacture's specified receiver input, the transmission performance of this link is adequately established.

Of course we must address the problems of optical splitting or coupling to feed more than a single node, or more than one receiver location. This function, splitting energy to feed two or more legs, simply introduces loss into each leg, and that loss must be added in developing the lightwave level input to any receiver fed off that spur.

Note that this process, simple calculations of transmission losses, determines the performance of that link quite adequately, and greatly simplifies the transmission predictions or engineering processes themselves. It also means that establishing the signal levels throughout, on a long term basis, reasonably assures acceptable transmission performance through the link.

Accommodating Link Loss Variations

Lightwave terminal equipments are generally specified for operation and use together, that is, transmitters and receivers of the same manufacture are intended for use together.

Lightwave transmitters, for example, will be specified by the manufacturer to present some stated bandwidth for use, to present some discrete level of transmitter output power at a given lightwave frequency for coupling into the interconnecting optical fiber, and the number of analog television signals that can be accommodated will be stated. Receivers are specified to produce a given level of transmission performance when those units are presented with a given level of input lightwave signal.

But all lightwave transmitters do not have the same output, although higher power output units may cost more of course. We can provide, and most manufacturers do supply, lightwave transmitters with different output capabilities. Using the same lightwave frequency, and in conjunction with the same lightwave receiver, this variety of transmitters will all supply the same transmission performance but make possible different length systems, that is, they may all present different allowable loss budgets for the same end-to-end performance.

By specifying the output levels, we can accommodate systems of different length or composite loss. Logistically, this might mean that a larger system required a number of different transmitters for installation, and stocking spare units would impose the same variety, since all transmitters are not interchangeable.

We might reduce this variety by using all the same transmitters, at the highest output level, and tailoring each optical fiber link to have the same, or nearly the same, lightwave loss by inserting an optical attenuator at the receiver input as required. In this manner all links would have the same, or nearly the same, performance, and logistics would be improved even at some cost penalty. Variations might reduce the variety of transmitters somewhat and resort to some level of optical attenuation as well.

It may be possible, in some cases, to pay a premium for a somewhat lower loss fiber in longer links, thus reducing the link loss somewhat. It is also possible that the link loss might be relieved a bit by selecting a different operating lightwave frequency where the fiber losses were lower per unit of length, but this seems somewhat improbable.

Of course the architecture of the system might also be manipulated. If we originally desired to feed two receivers say, with an optical splitter in the link and one transmitter, we could simply alter this design to eliminate the split and it's associated loss entirely, by using a separate fiber to feed the second point. This may not always be the most economical solution, or even the most desirable, but it could accommodate a particularly long fiber link.

Assuring Lightwave Receiver Input Levels

What remains to be done then, is to select and calculate the composite transmission losses of the interconnecting plant itself, so as to assure that the receiver input signal level, and the performance that level guarantees, is completely acceptable.

These composite transmission losses may include fiber loss per kilometer, some estimate of splicing requirements along with individual splice loss allowances, and any optical splitters or couplers that might be inserted into the interconnecting fiber.

Such a development is usually called a lightwave link loss budget, and may include some allowance for error or service restoration splicing. Remember that lightwave receivers do have some inherent tolerance to minor variations in input signal levels due to their own dynamic range.

If this process is strictly adhered to, then the transmission performance of any lightwave link can be readily established with acceptable precision. We are obliged to state the transmission performance between logical element interfaces, that is, between the input and output of the lightwave link itself, so that the performance between these is not only established, but can be demonstrated and verified as achieved when that element of a system is actually constructed. Establishing this performance is also essential in maintaining that same performance long term, and such demonstrations may be periodically performed as well.

Applying Link Loss Budgets

In order to familiarize ourselves with this process, perhaps we should do a few exercises. The reader is strongly cautioned that the figures used in these exercises are purely arbitrary and perhaps conservative, and they do not reflect the actual numbers that might be encountered in real applications. The figures used for fiber losses, optical splitter losses, indeed the figures used for lightwave transmitter and receiver input and output levels are fictitious, and were selected to facilitate the mathematical calculations that are required.

We will assume that a number of transmitters are available from a manufacturer, each meeting the same specifications under the same channel loading, but each having different lightwave outputs. We will also assume that any of these transmitters, employed in a link that presents the same, or nearly the same, lightwave input to a receiver of that same manufacture, will produce link transmission performance that is acceptable and within link specifications.

Lightwave transmission levels may be stated as an absolute power level, in milli-Watts (mW) for example, but we can also call out these levels as a power ratio with a reference if we use decibel-milliwatt (dBm). Zero dBm equals one milliwatt. We will use dBm for signal levels and use decibels (dB) for transmission losses. Then link calculations are quite simple. We directly subtract losses in dB from levels in dBm, just as we have learned to do in coaxial systems.

We will, for these examples, apply the following arbitrary performance specifications:

Fiber loss = 0.4 dB per kilometer of length

Fiber connectors = 0.50 dB each (2 required for each link)

Fiber splices = 0.2 dB per kilometer (includes repair allowance)

Optical splitters = 3.0 dB

Optical receiver input = - 3.0 dBm (with nominal dynamic range)

Maximum Transmitter output = + 12.0 dBm

Exercise 1. The optical link is 6 kilometers long and requires an optical splitter to serve two receiver locations.
What transmitter output is required?

Fiber loss is 6 X 0.4 = 2.4 dB
Connector loss is 2 X 0.50 = 1.0 dB
Splice losses are 6 X 0.2 = 1.2 dB
Splitter loss = 3.0 dB

Then total link losses are 2.4 + 1.0 + 1.2 + 3.0 = 7.6 dB

If receiver input is fixed and must be - 3.0 dBm, and total link losses are 7.6 dB, and the transmitter output level is the only factor we can manipulate, it must be + 4.6 dBm or nearly so.

This example included an optical splitter to serve two receiver locations. The splitter loss applies equally well in both legs, of course, but one assumes that both receivers are not located at the same point, thus both locations do not encounter the same length of fiber or the same fiber losses. Indeed one location may incur additional splicing loss as well. The end result is that at two separate locations, two lightwave receivers may not receive the same lightwave input. This condition is entirely due to the additional length of fiber, and perhaps fiber splices, that one location had to transit.

If the distance and fiber losses were only nominally different, perhaps no remedial action at all would be necessary, relying instead on the dynamic range of the receivers themselves. Certainly one transmitter cannot be changed to satisfy both locations. If, on the other hand, the distance and fiber loss differences was gross, perhaps an optical coupler should be used instead of a splitter. A coupler allows discriminate signal distribution rather than simply presenting each leg with half the input signal.

Exercise 2. This example requires one lightwave transmitter to serve only one receiver, but the distance at which that receiver may be acceptably located is unknown.
All losses, etc. are as before.

Max. transmitter output = + 8.0 dBm
Connector loss is 2 X 0.50 = 1.0 dB
Receiver input = - 3.0 dBm

If transmitter output is + 8 dBm and two fiber connectors are required, one at each end with a combined insertion loss of 1.0 dB, then the transmitter output level is effectively + 7 dBm. If the receiver input must be -3.0 dBm, then the total allowable link loss is 10 dB.

Fiber loss is 0.4 dB/km and splicing losses is 0.2 dB/km, this equals 0.6 dB of loss per kilometer. Link length, or the allowable distance out to the receiver location, is 10 divided by 0.6 which is 16.6 kilometers. At that distance, and with those levels and losses, the transmitter and receiver should produce the performance quality that the manufacturer specified for that equipment.

Readers are cautioned to read equipment specifications carefully before applying them. In some cases, for example, a manufacturer may specify transmitter loading assuming that some of those channels applied are digitally modulated and some are analog modulated. He may even state that digital channels are at a lower RF input level. This presents no difficulty if both manufacturer and user mean and understand the same things, but it is a potential point of confusion.

Coaxial Cable Extension Performance Development

This element of a hybrid system is quite straight forward in its development, and is adequately covered in earlier Chapters of this text. The methodology involved is exactly the same, and the prediction and verification of results is also. Certainly readers should be thoroughly familiar by now with the terms such as C/N Ratio, Composite Triple Beat, etc., and their usage.

Since, in a hybrid system, we anticipate several coaxial extensions, the cost of each such extension will be a significant factor.

It is possible, even probable, that the RF amplifiers used in hybrid system coaxial extensions will not have quite the same amplifier gain as conventional line extender amplifiers do. This is possible because the cascade of these units is distinctly limited, and the additional distortion that higher amplifier outputs impart might be quite acceptable in conjunction with the noise and distortion of the optical link itself. Of course if the signal levels are somewhat higher in these RF broadband extensions, then the cost efficiency of such extensions would be higher also.

Distribution System Specifications

If we have an improved overall transmission system in the hybrid configurations, then this can be translated into better performance specifications and such improvements will be most welcome in expanding system transmission capacity.

Note that, unlike conventional all-coax systems, hybrid systems do develop almost the same quality of signals, as well as almost the same signal levels, for all subscribers, regardless of distance from the Head End. The only variation would be the number of coaxial RF amplifiers that a subscriber's signals passed through.

It is not the intent of this text to present either equipment or system performance specifications. We are primarily concerned with the development of a systems performance as the cumulative effect of a number of devices or elements. If the reader understands such contributions and their relationship, then he or she can manipulate the individual elements involved so as to arrive at any desired performance.

Overall hybrid distribution system specifications are generally accepted to include the following items:

System C/N Ratio (C/N)
Composite Triple Beat (CTB)
Composite Second Order Distortion (CSO)

Worst case subscriber performance in hybrid systems is often taken to be 48 dB C/N Ratio and perhaps - 53 CTB.

It follows then that individual element specifications should be compatible with these same items. Note that the element specifications represent the transmission performance of that element, and that technical limitations of a particular element alone must first be addressed and resolved. An example of this would be the loss budget and compliance with transmission levels for the lightwave link itself, and this compliance would be necessary and vital in maintaining the lightwave link transmission performance. You have to determine and resolve the lightwave link itself and this is equally true of any coaxial cable extensions of course.

Summary

Hybrid systems are much easier to design and fabricate because the engineering of such systems is largely a matter of accommodating link losses and preserving or protecting receiver input signal levels. If this is done, then the transmission performance of such systems is assured by the manufacturer's performance specifications for the lightwave equipment itself, and the transmission performance of all lightwave links can be taken to be the same.

In effect, by calculating and not exceeding lightwave transmission losses through any link, of any length or composition, then we can comfortably establish the performance of any lightwave link or any hybrid system including such links. We don't really have to do any extensive link or system engineering beyond this.

It is practical and desirable to make all RF coaxial extensions of equal amplifier cascade, and they may be less than that without any adjustment at all. This presents economies in long term maintenance even if some few amplifiers or extensions are not fully utilized or individually at maximum cost effectiveness. Hybrid systems are also much easier to maintain long term. All that is required is to verify that transmission levels, both at lightwave and at RF frequencies, are at or nearly at those initial designed levels. Because there are fewer individual pieces of equipment involved in hybrid systems, this is a relatively simple task, at least it is when compared to 30 or 40 RF amplifiers in cascade as in many all-coaxial systems.

The reliability of service to subscribers is dramatically improved in hybrid systems because each fiber fed node, with it's associated RF amplifiers, is completely isolated from any other node both as to operating power and as to common equipment.

Hybrid systems offer the extension of usable bandwidth, and consequently increased transmission capacity, without imposing the severe performance degradation that all-coaxial systems did, and hybrid systems accomplish this with not only extended bandwidth possibilities, but with improved transmission performance as well.

Chapter 29

System Operation and Maintenance

There are a wide range of tests that can be made on a conventional RF broadband coaxial cable system, and this has certainly been compounded by the introduction of lightwave transmissions on optical fibers. There is also a very wide range of sophistication and costs in such testing. We cannot hope to adequately cover the proliferation of test equipments or techniques in a single Chapter of this text, and many excellent sources of detailed information already exist anyway. And this text was not intended to be a manual of test procedures.

Instead, we will focus on a philosophy of approach rather than on any series of specific test operations or procedures. As was true of system designs, no single maintenance program, and no specific test procedures, will best serve all situations.

Transmission Quality Assurance

Separate and apart from proof-of-performance tests, annual or periodic transmission measurements, or field engineering tests associated with new installations or additions, a regular, sustained plant management program at a lower level of sophistication is essential, if the *quality of transmission* throughout the system is to be protected over the long term.

We will differentiate between trouble analysis and repair functions, and system maintenance, because they are not really one and the same. A total outage or service interruption, for example, is a trouble condition and restoration of service certainly carries the highest possible priority. But such restorations have little to do with the long term maintenance of transmission quality.

All manufacturing processes include, as a matter of standard practice, quality control or quality assurance programs, both for incoming parts or assemblies, and for completed products. In the operation of a telecommunications network, we must be equally quality oriented, if not more so.

CHAPTER 29 SYSTEM OPERATION AND MAINTENANCE

General Discussion

To completely evaluate the performance of any transmission or, in this case, distribution system, it is desirable to measure all the operating parameters of all the system elements that we have, throughout this text, presented and discussed. This would include noise, system frequency response, and all intermodulation distortion products. Some of these are much more difficult to measure than others, and the sophistication required of personnel, and the cost of suitable test equipments, can be quite high. Sustained and frequent testing at the highest possible levels may not really be essential for day-to-day maintenance purposes.

When we introduce lightwave links in *hybrid system* configurations, for example, we have substantially reduced the complexity of those systems, and surely we have reduced the number of contributory sources of noise and distortion.

If the system design and construction has been carefully developed and complied with, and all component equipments perform as individually specified, the overall system performance will most probably remain unchanged, or drastically so anyway. There is little rational reason to expect that an RF amplifier, or any other discrete component, will dramatically change its Noise Figure for example, or its intermod contribution either, at least not without some significant external *changes in transmission levels* through that system.

Upon completion of a construction project, an exhaustive test program to verify engineering predictions, and system transmission performance, would certainly be in order. Beyond this point however, if operating signal levels remain unchanged, then it is reasonable to expect no gross changes in overall performance, even over a longer term. It is difficult to even imagine some change in component or element performance that would not be evidenced as a change of transmission levels.

It may be prudent, even necessary perhaps, to periodically reassure ourselves that end-of-system transmission quality remains unchanged and satisfactory, but we can certainly limit extensive and sophisticated testing to infrequent "quality assurance" schedules, and this is equally true of hybrid systems that include lightwave links.

We should monitor transmission levels rather religiously however, since the extent of degradation from signal level variations could be severe, and is the most probable scenario. Fortunately, measuring signal levels throughout a system is the least sophisticated operational test to perform, and can be easily and inexpensively incorporated into all the other normal system operations such as new subscriber installations, or routine house service complaint calls.

Even in the supposedly ultra-sophisticated lightwave links themselves, most equipments permit easy verification of RF signal level output, and in many cases, verification of lightwave input levels through DC measurements at receivers as well.

Simplifying System Maintenance by Design

Certainly in any distribution system, be it all coaxial or hybrid in configuration, the *long term maintenance*, and we could substitute *transmission quality assurance* here, must be a primary consideration. We not only ought to consider practical and adequate techniques, we need to configure and construct plant that favors those techniques as well.

One practical approach is to establish several permanent test locations along the system. Such permanent test facilities might include, in aerial plant, short extensions from test ports or even from unused tap ports, of RG-59 coaxial cables down the pole to a convenient height above ground.

Such semi-permanent test points should be located where vehicle access is easy and safe, where vehicles need not intrude on normal traffic, and ideally, where test could be conducted within the vehicle cab itself by simply uncoiling or extending the in-place coaxial test cable. At such points, measurements of all signal levels are easily conducted, even in inclement weather, and if recorded, would constitute a record of proper operation to that point in the system, even during ambient temperature excursions.

Such tests are simple and completed with little interpretation and sophistication, and may well serve a useful purpose during service interruption operations as well. If each such visit included time of day, ambient temperature, and an initial or signature of the performing technician to impose some degree of accountability, they might have sustaining value in maintaining or restoring transmission quality.

The introduction of lightwave links has substantially reduced RF amplifier cascades of course, and perhaps a ground level test point of this type could be located at each lightwave receiver location, where system service nodes originate.

The name of the game is not to perform a multiplicity of high tech and repetitive tests unnecessarily, but to generate a feel, over time and temperature variations, for proper system operation and performance with the least expenditure of time and money. If such a *quality assurance program* is adopted, it makes an ideal vehicle for all levels of technicians to participate as well, and exposes all people, including new people, to the philosophy of transmission quality concern. Don't just use lead technicians for this work, use everybody in turn, even for routine reports or measurements. Then all your people will be familiar with the test procedures, and will be comfortable with normal, proper operating levels within the system.

It is beyond the scope of this text to detail all possible test techniques, especially as they might relate directly to a practical maintenance program, but it would not be inappropriate here to briefly discuss a few familiar or more commonly employed methods.

Sweep Generators and Oscilloscopes

One efficient method of measuring frequency response across a broad band of spectrum is the use of a sweep generator in conjunction with an oscilloscope for response display. This greatly facilitates any response adjustments that might be available such as amplifier *tilt* or *slope* controls, for example. It can be useful in verifying the effectiveness of system thermal controls or the effects of seasonal ambient temperature changes on frequency response, and *sweeping* through a hybrid system to a point in the coaxial section can also verify response through any incorporated lightwave links.

On working plant serving subscribers, the sweep testing technique requires special care if the sweep signal itself is not to introduce interference in the signals received and viewed by the subscribers. For construction operations, perhaps sweep testing finds its most useful application in the initial adjustment of new plant or plant additions.

RF Carrier Level Measurements

Without question, the most widely conducted measurements on broadband systems are *RF carrier levels* themselves. These tests employ frequency tunable voltmeters commonly called Signal Level Meters (SLMs). An SLM permits us to measure the amplitude of any individual RF carrier within the dynamic range of the meter itself. TV visual carriers, aural carriers, FM signals, or regulatory pilot tones can all be measured individually, and in many cases, within the limitations of the particular unit, it can also measure undesired carriers or interfering beats, as well as spurious signals.

Most units provide audio demodulation and channel monitoring capability, and some include video demodulation as well. These units permit AC hum modulation measurements and provide some carrier-to-noise capability. It is possible, by measuring and recording all system RF carriers within a broadband system in turn, to plot the frequency response of the system as well, although this is a somewhat time consuming process as compared with the sweep testing technique.

Disadvantages inherent in SLM testing are long term calibration for measurement accuracy and their somewhat fragile nature. Advantages are their portability (most are battery operated) and the relative simplicity of use, particularly by unsophisticated service personnel. It is general practice for installers of new stations to make levels of signal tests, using some level of SLMs, and recording and reporting those levels to management. They are also relatively low in cost compared to other test equipment.

Spectrum Analysis

A spectrum analyzer will visually display a broad band of spectrum, and signals within that spectrum, desired or undesired, will be displayed with their relative amplitude and frequency readily apparent.

Less satisfactory for level or slope adjustment of individual amplifiers, or for hum modulation measurements, the spectrum analyzer is a great help in identifying interfering signals and in measuring C/N ratios.

Disadvantages include its high cost, its delicate and bulky structure, and the significant level of technical skill or training required to use it and interpret it correctly.

Visual Evaluation of Television Pictures

The old, reliable TV set itself is an extremely useful tool in any maintenance program, and in some cases, is almost indispensable for trouble analysis and system restoration. An experienced or *trained observer*, and such skills are rather easily acquired, can recognize and identify noise, hum, cross modulation, beat interference, and some other forms of picture degradation. Often this identification in itself will lead to some isolation of a trouble condition, for example, a *windshield wiper* effect on the TV screen is most probably not a head end problem, and if present in only some sections of a system, may lead to rapid isolation within the cable plant itself.

The disadvantages of a TV set are its bulk and weight, its delicate structure, and its reliance, to some degree, on the availability of commercial power. The major advantage is that it is the final arbiter of the transmission system. The picture is the product that any cable system offers its subscribers, and no other normally used technique can examine the pictures themselves.

Electrical Measurements

Measuring the AC power and voltage levels and the DC amplifier operating voltages is essential in setting up new plant and in trouble shooting operating systems, but they have only limited merit in maintaining transmission quality. Almost any good volt-ohmmeter (VOM) has application here, and some SLM units also include this capability.

Lightwave Links

It is possible, of course, to measure the level of lightwave signals as they are input to the interconnecting optical fibers or as they exit the distant end of those fibers. Such measurements require the use of optical power meters, but more importantly, they require the disconnection of operating fibers in order to make the measurements possible. The delicate nature and uncertainty of optical connections introduces the distinct possibility of improper re-connection of such fibers, as well as imposing a complete interruption of service on operating fibers. Such measurements may very well make sense to prove in new facilities, but have little value or merit in routine quality assurance, and should only be resorted to if there is good reason to suspect trouble of some kind.

Most lightwave terminal equipment has other test capabilities built in, and for purposes of routine maintenance, such measurements at lightwave frequencies are neither generally required nor recommended. If other test functions are available however, particularly if such measurements do not disturb or interrupt normal service, they may very well have a place in the regular or periodic measurement and logging program.

System Maintenance Test Points

The value of a series of measurements made at the extremities of a system is self-evident. It is equally useful however, if a program could regularly produce performance data from several discrete points within a system. A program that took logically or geographically identified sections (nodes if you will) of a system and facilitated separate evaluation of each such section would have real merit.

Such a test program, periodically conducted by all field people, would thoroughly familiarize all people with normal signal levels at all of these points as well as monitoring system levels, and thus performance. It also serves to establish and standardize the tests for all field people when the system is functioning properly, not on a *call out* basis when the restoration of service is paramount. Tests of all carrier levels by all people should include tests of signal levels as they leave the Head End as well. Many system Head Ends do not prominently identify either the system output test point, or the signal levels normally present at that test point.

You can't predict when a problem might develop in any system, and you surely can't always predict the level of responding personnel that might be available. All field personnel should be familiar, with routine tests conducted periodically under normal operating conditions, with the signal levels at the Head End, and at several points within any system. This may not only monitor normal operation, it will contribute to faster and more accurate analysis and location of troubles and outages as well.

To instill a sense of *professionalism* and *accountability,* all personnel should be required to sign or initial all test results, and time of day and temperature might be valuable for later analysis.

This can be easily accomplished by establishing a number of permanent test points, preferably at ground level in aerial plant. The test locations should be determined not entirely for technical reasons, but should consider such factors as:

Can you drive directly to the test location?
Can the tests be made from inside the vehicle?
Is it completely safe to park the vehicle there?
Is pulling back into traffic hazardous there?

The objective is to make the test points safe, comfortable, and convenient so that the tests themselves, whoever made them, will be made thoroughly, accurately, and with a high degree of repeatability.

Recording Test Data

If a maintenance program is to be cost justifiable, it should do more than just tell a technician that at that moment in time, the signal levels were at that level, at that particular point. Significant changes in signal levels, changes from the normal operating levels, are what we're looking for here, and much of the value may be lost if normal test results are not recorded and evaluated. It cannot be over-emphasized that all such reports should be completed and turned in to management for evaluation. This not only puts potentially useful data, which certainly has cost both time and effort to acquire, in the hands of the responsible people, it imparts a sense of meaningful participation to those field people actually collecting the data through tests.

Some common sense and flexibility is certainly required here. For example, if a bad wind storm had created a lot of plant damage, the scheduled routine maintenance tests should surely be postponed. It is not the time cycle of the test routine that is important, not every second Tuesday for example, but every second or third week might be appropriate. It also helps if routine tests of this nature are scheduled for lighter work load periods if possible, so that they will not be casually dismissed. Mondays for example, when routine subscriber service calls may have accumulated over the weekend, might be a poor maintenance schedule.

It is strongly suggested that *all personnel* be utilized in such a program of repeated testing. The general practice may be to utilize one or two more experienced personnel for such functions, but this is an ideal opportunity for training, for familiarization for all personnel with this particular system, and its normal operation, as well as practicing meticulous test techniques. Even station installers might be usefully employed, and could acquire new skills and understanding.

Evaluating Test Data

The data produced by such a program will provide an overview of the entire system performance across a base of time, and through seasonal temperature changes as well. Presumably adequate system self-regulation, in the form of Automatic Gain Control for example, has been established and correctly installed. Then across normal ambient temperature variations, signal levels should not experience gross variations. Given test data taken over time, gross level variations might be evident, and might be indicative of incorrect AGC or ASC operation. *Data analysis* would show this.

As important as the repeatability and regularity of the tests themselves, is a program for reviewing the collected data is equally important. There is little redeeming merit in a test log that religiously collects data if that data is not reviewed and analyzed at all.

There is another base of information that, correctly used, can be extremely valuable in any quality assurance program, and that is *subscriber* trouble reports. Some operators seem to regard subscriber reports as an unavoidable nuisance and casually fill out trouble reports with simplistic explanations of the trouble actually found, or the corrective action taken, if any.

Undoubtedly some subscribers are unnecessarily critical or chronic, but it is too easy to adopt a philosophy of disregarding such complaints entirely. Let's try a brief scenario here.

A fairly extensive system is exposed to very cold ambient temperatures during winter nights. This system has a number of AGC stations that have become incorrectly adjusted over time, and although the units themselves are completely operational and are correctly spaced along the cable route, system self-regulation cannot compensate sufficiently for the temperature extremes experienced.

The result is lower cables losses, due to the colder temperatures, and higher signal levels, due to the inadequate AGC action. Subscribers in one section of this system experience more intermodulation distortion from these causes during the cold night hours, and report poor reception quality. There is no service outage reported, and the complaint is held over for the following work day. This is a legitimate problem and subscriber complaint.

A system technician receives the complaint on the morning of the next work day and is dispatched to the subscribers premises. But this individual may not leave the office for some time due to other duties, or may stop for a coffee break on the way there. He does not arrive at the premises until 9:00 or 9:30 in the morning, and the night temperature has already risen say 10 degrees or so. The system is now within the incorrectly established, but operational, corrective range of the system AGC units, and the technician finds no improper signal levels to be present. Of course the temporary contributory high levels, and the resultant higher intermodulation contribution, may have been some distance back in the system anyway, and perhaps subsequent AGC units, correctly adjusted, did make proper compensation and did produce correct signal levels at that premises anyway.

In any event, the technician finds measured signal levels at the station to be correct and within system specifications, and a careful examination of TV picture quality indicates no unusual distortion is present. The technician correctly and conscientiously records and reports this visit as a *no trouble found.*

But there is a trouble, or at least an abnormal system condition, isn't there?

Since the original condition, the improperly adjusted AGC units somewhere in the system, have not been corrected, the condition still exists and the subscriber trouble reports may persist. This may not be an unreasonable scenario at all. It is only the subsequent analysis of repeated subscriber reports, and perhaps other "no trouble found" reports, that will initiate further investigation.

The above scenario is only one example where the subsequent review of reports can contribute to system quality assurance. Perhaps, given a series of periodic signal level measurements as discussed earlier, and if such reports included temperature data, this condition would have become apparent to the operators, and might have been corrected before any subscriber complaint or dissatisfaction were registered.

It may be a bit subtle, but *subscriber reports*, coupled with professional analysis, can be a significant part of any quality assurance program, and you may find maintenance program substituted here in some literature.

Service Restoration Operations

In the long-term operation of any Cable Television system, be it all coaxial, or hybrid fiber coaxial, we can clearly identify two major functions. The first of these is maintaining the continuity of service to the subscriber, and this includes emergency responses to service interruptions such as amplifier failure, disruption of operating power, damage to physical plant such as cables or fibers, etc. The second, of course, is the maintenance of service quality, and this might include periodic testing, response to quality affecting technical problems, or seasonal signal level adjustments.

The manner in which we address each of these may have some impact on long-term operating costs of course, but will also impact on subscriber service satisfaction, and indirectly, on subscription revenues.

We may logically assume that service interrupting outages will predominately be massive in nature, that is, they will generally affect a significant number of subscribers. Quality of service complaints may also be massive of course, but will largely be confined to one or a few subscribers alone.

Quite obviously, total outages will have the greatest priority and will constitute the greatest number of emergency or *call out* after hours responses. A good basic philosophy in such cases follows a precept of physicians. The doctors primary obligation is to do *no harm*, to heal or correct if possible of course, but in every case to do no harm to the patient. During service outages the responding people are subject to a number of pressures. It may be inclement or raining, it may require hours, there is a constant pressure to expedite the restoration, etc. In the press of these operations, and in the face of all these pressures, the technician may be inclined to hurry the work, perhaps superficially readjust levels or self-regulation.

But often, perhaps too often, the restoration and any subsequent adjustments made under these adverse emergency conditions, are accepted and become final adjustments. It is assumed that if that individual is able to locate and identify the primary cause of the outage, that he or she is competent to make correct remedial adjustments. Sometimes this is not the case. Sometimes the only personnel available for the call out were not fully qualified, and perhaps inadvertently leave or introduce some new problems into the situation. Service restorations should always be looked at again in the cold light of day, or verified by more competent or more experienced people.

Fault Location

Obviously, in the case of an interruption of service, the fault must be physically isolated or located. The ease or rapidity with which the location is determined will certainly have an effect on the duration, and consequently on the impact, of the outage itself.

A common practice, in any transmission system, is to sectionalize the fault by visiting and ascertaining correct operation at a number of intermediate points. If these points coincide with the test points used for *periodic quality assurance* testing as described earlier, incorrect or completely absent signal levels should be readily detected.

One disadvantage of such procedures is the possible disruption of properly operating equipment at such locations. Each such test should establish the service interruption as being ahead of that particular point, or in the remaining portions of the system, but each such test also involves visiting and perhaps opening equipment housings at several points. All such disturbances must be carefully restored at that time or subsequent troubles may be introduced.

By sectionalizing, outages can be localized, and eventually pinpointed. The introduction of lightwave links, followed by limited RF amplifiers in cascade, greatly simplifies and expedites the location of service outages, and test conducted at a lightwave receiver, for example, may already sectionalize an outage into coaxial cable plant that includes only 2 or 3 RF amplifiers. Such tests may, on the other hand, isolate the outage into the lightwave link itself. In effect, in hybrid systems, the locating of total outages should be much simpler and faster, and may obviate entirely the need, use, and cost of RF amplifier status reporting systems.

In extensive coaxial systems with many amplifier stations, even with a tentative or positive fault location through such status reporting capability, the response mechanism still requires traveling out to that location to effect the restoration. If it were possible, while driving out along the coaxial cable route, to produce a positive indication of RF transmission continuity along that route, or equipment locations along that route, the elaborate and costly status monitoring subsystems may be greatly simplified or even eliminated entirely.

One technique to accomplish this could be a method of discriminate, controlled and limited, *intentional leakage* of a fault locating signal from within the operating portions of the cable system itself. We might adapt some of the techniques developed to monitor and measure RF leakage from within the cable system.

For fault locating purposes, we could temporarily inject a special test tone which was distinctively audio modulated, perhaps in a vacant portion of the commercial FM band. At selected equipment locations, or at idle system tap ports if necessary, we could couple some of the system RF signals through restrictive band pass filters to a small *radiating element.* The filtering, not necessarily sharp or deep, would restrict the radiated signals to a narrow portion of the system transmission bandwidth, to those portions that are least offensive or already contaminated by other free space broadcasting facilities in the area. The practical effect would be some distinctly limited radiation, perhaps one hundred feet or so, of a distinctively limited spectrum.

The detection of the radiated test signal would be a receiver in the service vehicle, perhaps an inexpensive FM receiver. Tuned to the test signal carrier frequency, this receiver would detect signal from each radiating pattern in turn, and would produce a distinctive audio tone or *beep* as the vehicle passed through the radiation pattern at each location.

Such detection would occur, and the audible signal would be heard within the vehicle, as that vehicle passed through, at speed, each radiating locations pattern.

If there had been an interruption of cable plant continuity ahead of that location, then no RF signals would be present at that location, and this would include the test signal as well. Then no test signal would be radiated at that location, and the detecting receiver in the vehicle would so indicate as the vehicle was driven through that limited pattern or radiation. The receiver would not produce any audio *beep* at all, a positive indication to the driver that RF continuity to and through that particular cable location did not exist.

If, on the other hand, the outage was beyond that radiating location, RF would pass to and through that location and that would include the test signal carrier. It would be filtered and presented to the small radiating element, and that radiation would be detected within the vehicle, producing the audible "beep" as a positive indication to the vehicle driver that RF continuity to that point in the system did exist. Again, all indications of RF continuity or the lack of it, within the cables system itself, would be positively indicated as the vehicle, without pause, drove along the cable route *at speed*.

If actual detection of RF presence within the cable system were limited to a few select locations or system extremities, the absence of RF at these locations could be reported back to the system head end automatically as a relay contact closure by any of several means, by radio, a leased telephone pair, or even through the cable system return transmission path itself. Then that relay contact closure, detected at the head end and only present when RF was not detected at the extremities, could turn on the fault locating signal generator itself.

By the way, it could also report the outage to the system offices, or could actually dial through automatic dialing devices, the selected telephone numbers of technicians or managers at their homes. A technician might then respond directly, that is, since the fault locating signal had already been generated and applied to the cable system, and since the technician has been alerted to the outage, he or she could simply drive out to intersect the cable system itself and pass through any radiating pattern. The presence or absence of the audible "beep" on the vehicles detection receiver, would indicate whether the point of system intersection was past the outage point or not, and would direct the driver in the proper direction, toward the actual point of outage. What we have done here is to dramatically reduce the status reporting from a multiplicity of locations to a few key locations, we have reduced the complexity of those reporting stations to the presence or absence of RF signals alone, and we do not require any such locations to be digitally interrogated first, or to digitally identify themselves either. We are simply reporting on the transmission status of the system, and relying on the response mechanism, the travel out into the system that is required anyway, for the actual location of the loss of signal within the system.

One possible advantage of such an approach would be the unusual, but not unheard of, problem of more than one separate outages at two or more locations.

When a technician responded to an outage alerted and located in this manner, and effected the necessary repair, RF continuity would be restored through the system. The detector and reporting device at the system extremity would respond to the restoration of service, would sense the renewed presence of RF energy, and would automatically turn the temporary fault locating signal off.

The technician, upon returning to the vehicle, would note the absence of the fault locating tone altogether, and would have positive assurance that RF continuity to the end of the cable system had been restored. Suppose there were two or more outages in a conventional system? The technician may well have found and restored service through the first, and assumed that continuity through the entire system was restored also, and gone home, thinking the work had been completed. One suspects that such may have actually occurred in the past.

Again hybrid systems, with fewer locations involved, probably do not justify this sophistication, but it may help in understanding how systems operate and are serviced. Although there are, to our knowledge, no such detection and location systems in common usage today, the author does hold a U.S. and Canadian patent for this technique.

Keep in mind that any cable system, coax or fiber/coax, or even older systems using older equipment and offering less transmission bandwidth, would be capable of such modification. The radiating devices are passive in nature and require no operating power, there is no interrogation at all, and locating devices can be judiciously applied anywhere, and with any density, in any system. Of themselves they would be inexpensive and trouble free.

Protecting System Quality

At first glance, since service personnel are already at the location where the service outage occurred, it seems reasonable, even during inclement weather or late night hours, to rely on those same personnel to not only make any required equipment substitutions, but to properly adjust that equipment at that time. This is a generally accepted practice in the industry today.

This does escalate the relatively simple service restoration function to a *quality affecting* level. Perhaps the action phrase here is *proper adjustment.*

Given a high level of servicing experience and knowledge, this may present few problems, but we cannot dismiss the consequences of improper adjustment quite so lightly. Adjustments that affect transmission quality really affect the product itself, don't they? The product for sale is picture quality and variety of course, and it is somewhat disquieting to place the quality of that product into the hands of a service technician, particularly when that technician may have been the only *warm body* that was available for emergency call out at that time, or may have only marginal capability.

Just what is involved in equipment adjustment?

First we introduce quantitative measurements using a meter of some sort, with concern for the interpretation of those measurements and perhaps the calibration of the meter itself.

In some systems, trunk-feeder plant for example, there may be several different operating signal levels for different equipments. Someone less familiar with the system may introduce incorrect levels inadvertently.

Such maladjustments, however small, could compound over a period of time, when several such improper adjustments might be required. The end result might not introduce a service outage, of course, but a gradual degradation of the transmission quality, and thus of the product itself.

Consider the replacement of an automatic level control (ALC) unit. Locating the point of failure is essentially the same process, but adjusting the replacement unit correctly is a higher level of responsibility. The correct adjustment must take into consideration the temperature of the coaxial cable itself, since this affects transmission losses and input signal levels to the unit. The unit may well be normally providing some level of correction.

Confusion, error, or complete omission of any compensating correction can have a substantial effect on end-of-system quality as the system is subsequently exposed to normal temperature excursions.

Sometime back, the author, at an industry gathering, briefly polled eight or ten experienced CATV engineers with this question.

Of all the automatic control units in service, in all the coaxial cable plant in use in this country today, how many units might you assume to be improperly adjusted?

Keep in mind that these were all experienced people with extensive experience in the design and operation of Cable Television systems. Ask yourself this same question.

The consensus of opinion among the experienced people who we asked was that 55 percent would be incorrectly adjusted, with some individuals anticipating as high as 65 percent. *What was your response?*

By design, in all of that plant, the automatic control units had been installed as frequently as required. Perfectly sound engineering judgement was applied, and the factors of cable lengths and anticipated normal temperature excursions, had been considered. Automatic self-regulation was introduced sufficiently to accommodate this, but the engineering judgement was based upon each device actually providing some consistent capability and range of correction, was it not? And those devices were operational, they were all capable of providing that range of compensation.

Improper adjustment during the restoration process had degraded the self-regulation capability, and the system and the product was at risk.

Given larger revenue base operations that may support some depth in technical staff, the problem may not arise at all. In smaller operations however, we enjoy no such assurances, and eliminating or minimizing maladjustment is certainly a cause of concern.

Ideally, equipment replacement would require a minimum of field adjustments and as little personal judgement as possible.

Systems would tolerate a wider range of signal level variations from any cause, be it temperature changes, improper equipment performance, or even incorrect equipment adjustment.

Can such ideal conditions be achieved? Perhaps not entirely, but we might be able to improve the situation somewhat.

Simplifying Maintenance

In the design of any system, ignoring economics for the moment, it is possible to design an entire system utilizing one identical type of amplifier throughout, and to operate all system amplifiers with identical input and output levels. We have discussed, earlier in this text, just such operations in the single-cable designs. The logistic advantages in spare equipment alone are quite attractive.

If the argument against using automatic control units has validity, and those arguments are largely unit cost and complexity, we might also design for a higher level of system self-regulation without violating the principle of identical equipment and operating levels.

If all amplifiers are, in actual practice, presented with identical input levels or nearly so, and produce identical output levels, perhaps replacement units for service restoration spares mighty be preadjusted under controlled and ideal conditions beforehand, and employed in restoration operations as “plug in” substitutions requiring no field readjustments at all.

If such a technique were practical, it would relieve us of the necessity for precise field measurements, personal judgements or evaluations, and careful *quality affecting* equipment adjustments as well. We may be able to effect restorations with lower level personnel without undue risk of quality compromise.

In conventional trunk/feeder system however, the philosophy of a single amplifier and operating levels universally applied throughout a system is unrealistic. The economics of trunk/feeder designs is most persuasive. Then the introduction of different types of equipment, and different operating levels, in different portions of a system is inevitable and required. So be it.

We might still introduce the new techniques of maintenance into portions of that plant, into feeder plant alone perhaps, and with beneficial effects. In smaller systems and in rural designs as discussed in an earlier chapter, we do utilize a single type of amplifier and we do operate all units at the same signal levels. The concept of no field adjustment replacement is certainly not an academic question in these applications.

Although a much higher level of system self-regulation is suggested, AGC at every station perhaps, the gain of all units (AGC, ASC, or manual) is taken to be the same, thus the practicality of pre-adjusted, plug-in, *no field adjustment* replacement equipment is more realistic. By design, system design that is, we might make possible a new long-term maintenance program that introduces less uncertainty to the transmission quality of a system. Of course if we do so, we also reduce the probability of subscriber dissatisfaction, don’t we?

Hybrid System Maintenance

Although much of our discussions may lend themselves particularly well to conventional coaxial cable plant with the associated cascades of a multiplicity of RF amplifiers, we cannot, and do not intend to, ignore hybrid systems in this discussion. But, as we have covered earlier, hybrid systems involve relatively few equipment types or locations. Although, in such systems, coaxial RF amplifier cascades may be limited to 2 or 3 such units, those units themselves present an opportunity for direct, plug-in equipment replacement.

They are identical units, and all are operated with identical input and output levels, thus all have the same gain characteristics. Restoration operations may be simplified to establishing, at lightwave receiver locations where the transition is made to broadband RF transmissions, the correct levels of all RF carriers. Beyond that point, the substitution of inoperative equipment would be quite straight forward and would certainly introduce only limited exposure to system variations or errors.

Field Testing the Plug-in Replacement

Some years ago the author was involved in an actual field test program to evaluate the practicality of using “pre-adjusted” units for service restorations. This particular system was designed with AGC in every station of a single cable system, but the procedure would be essentially the same if the regulation density were every second or third station.

Amplifier input levels, by design, were established to be +10 dBmV, with all stations also providing +40 dBmV outputs. AGC units were specified to produce less than .5 dB output level change for input changes of + or - 4 dB. The units under test, in this case separate gain and AGC modules, were treated and tested as a set or matched “pair.”

The procedure was to set up and power on a test bench an amplifier housing. The unit under test, be it an AGC or manual amplifier, was equipped with a 0 dB pad and 0 value equalizer. Head end RF signals were presented to the input of the amplifier with all carriers at the design input level of +10 dBmV for a “flat” input.

In the manual mode, the amplifier was adjusted to have +40 dBmV output at Channel 13 (211 mHz) and with a 5 dB “tilt”, with Channel 2 (54 mHz) 5 dB lower. In the automatic mode, the AGC unit was adjusted to duplicate the above output conditions. Then an adjustable attenuator at the amplifier input was manipulated to introduce input levels both +4 and -4 dB from the design level of +10 dBmV.

Amplifier output levels were monitored during these variations, and the unit was adjusted to have the proper corrective effect under either input condition. This verified that the automatic control had been correctly set, at least for the ambient temperature of the test bench itself, and that self-regulation was operational.

The amplifier, consisting of both manual and AGC modules, was then considered properly adjusted for field installation. If the design had called for manual stations as well, they would have been adjusted in the same manner without the AGC unit adjustments.

System Installation Procedure

We adopted the direct substitution theory to apply equally well in the initial installation of these units in the system. The premise was if the amplifier input signals in the system did differ from the design input signals, and they might normally do that because tapping was heavy in that area and cable lengths were consequently shorter, or perhaps because cable sizes and losses differed, that was to be expected.

The input levels could and would be brought into agreement with the design levels through the use of plug-in pads and cable equalizers, or nearly so, just as they normally are in any cable plant.

At each location, a pre-adjusted amplifier unit was installed, and the input levels and the slope of those levels across the band of interest was measured, ahead of the RF input to the module itself. Cable equalizers and pads were selected and installed to approximate, as nearly as possible, the design input levels of +10 dBmV on all RF carriers.

Although output signals were taken at each amplifier, these were simply for verification purposes, and no further adjustment of manual gain or AGC modules was permitted or made as a function of amplifier installation.

The ambient temperature while this installation was made was the same, or nearly so, as the temperature during the bench AGC adjusting process, and no thermal correction was necessary at all. No sweep signal or other sophisticated testing processes were conducted, and amplifier installation was considered to be complete.

Field Installation Results

Certainly there was nothing difficult, startling, or revolutionary about the mechanical implementation of amplifier installations in this manner, but the bottom line is how did we make out? How did the end-of-system transmission quality measure up when we were all through?

The system involved 18 RF amplifiers serially connected, or in cascade as we say. All amplifiers were sequentially installed in exactly the manner just described.

The transmission performance achieved did correlate very well with the engineering predictions, and we concluded that even if we had, in the conventional manner, made field adjustments of each amplifier installed as we progressed, we would have seen no appreciable improvement on the end-of-system performance.

We didn't stop there.

Simulated Long Term Replacements

To simulate the long term replacement of units, we bench adjusted, exactly as before, as many additional amplifiers as we had on hand. As before, no field adjustment of substituted units was performed at all. As a matter of fact, no field measurements of signal levels were taken either.

At the and of the system, after a cascade of 18 units, we had an independent and well qualified engineering evaluation of all system transmission parameters performed after initial installation and after each incremental substitution as well.

We arbitrarily selected four amplifier locations in the cascade, and made direct equipment substitutions on a plug-in basis without any adjustments.

The end-of-system performance was unchanged.

We made a second substitution of an additional four amplifiers, again with no field measurement or readjustment at all.

The end-of-system performance was unchanged.

We continued the substitution process with an additional four spare pre-adjusted units.

The end-of-system performance changed slightly, on the order of one dB or less, not the signal levels mind you, but such factors as C/N Ratio and various forms of intermodulation distortion.

This change was evidenced only after 12 of 18 units had been changed out. Certainly this simulated the change-out of equipment over some period of years. If 12 units had been individually adjusted at the time of their substitution, we may well have introduced some change in end-of-system performance of a greater scale than one dB or less.

Fixed Gain Possibilities

The point of these tests was not that we had demonstrated a simplified procedure for system “turn on,” but that we had shown that equipment, individually preadjusted, could be indiscriminately introduced into a system, either massively as an installation process or individually as a subsequent service restoration substitution, without significantly degrading end-of-system transmission performance.

When we introduce lightwave links, with a dramatic decrease in the number of RF amplifiers in the coaxial extensions, we make direct substitutions of preadjusted equipment quite practical.

There is a tendency on the part of technical people to accept without question higher levels of sophistication, we think of the transmission system as a complex structure that demands complicated tests often. But the contributing factors in noise or intermod degradation are almost always evidenced as transmission level changes in the system, and these are both obvious and unsophisticated to detect.

Many readers may be reluctant to accept or endorse this lower level of sophistication, but the long term costs of preadjusted equipment replacements should not be dismissed lightly.

We suggest that if your personal experience creates a negative response, then take the time and effort to perform these same procedures even on a limited scale in one section of your system. Surely you can abandon this approach if your experience is negative, but just as surely you will reduce cost and perhaps improve quality if it is positive.

Replacing Failed Equipment

Whatever means is employed in identifying the specific equipment location which is responsible for the loss of service, the requirement now becomes a determination of which unit is inoperative, and a direct replacement. This determination or isolation does not demand a precise measurement of RF signals or, for that matter, of AC or DC voltages. The primary obligation is to reestablish RF continuity and service to the subscribers, and if signal levels are not right on the mark, it is surely better than no service at all.

Since outages often occur at awkward times, and thoroughly competent service people may or may not be available, the prudent system operator should expose a number of personnel to actual service restorations when possible, and if such people are not completely qualified to make final adjustments, they can and should be trained to effect simple service restoration. Better people, and more precise readjustments, are always possible at a later time, but immediate restoral of service, even slightly impaired service perhaps, has priority here.

If transmission "quality affecting" field adjustments can be minimized or eliminated by preadjusted units, system operators might find manpower requirements easier to satisfy, particularly in smaller, marginal installations. It's nice to have, and always use, fully competent people, but sometimes, and in some emergency situations, this is not a viable option. We might explore this further by addressing the second primary service function, namely protecting and maintaining system transmission quality.

Maintenance Objectives

Perhaps a brief restatement of the basic maintenance objectives would be in order.

1. It is desirable to reduce the sophistication of service restoration in all operating systems, so far as this is possible.

2. It may be practical to think of, and approach, fault location and service restoration somewhat separately from system equipment adjustment.

3. Hybrid systems do not necessarily impose higher levels of testing sophistication or more frequent testing either. In many respects they are much less complex, and thus easier to maintain.

4. Available personnel can often be easily trained and effectively employed in both long term maintenance and in service restorations.

5. The less complicated tests and procedures are, the higher the probability that they will be correctly conducted.

The basic idea is to “ruggedize” the system such that end-of-system performance is maximally protected both from natural events such as temperature, unpredictable events such as equipment failures, and cockpit trouble such as personnel doing too much or doing it incorrectly. We use the term “ruggedize” here in the same sense that the military uses the term “harden.”

Summary

What must be guarded against is a perfectly natural, but sometimes irrational, obsession with sophistication. We are not, and needen’t be, scientists or sophisticated engineers. Building and operating these systems for extended periods of satisfactory operation call for more common senses and practicality, than it does for in-depth technical knowledge.

Chapter 30

Subscriber Terminal Equipment

We will identify all devices and equipment associated with delivering service to the subscriber as *terminal equipment* and include in this category the cable tap itself. Although the tap is generally considered an integral part of the distribution cable plant, indeed it is often installed before a revenue-producing subscriber is assured, there are compelling reasons to include the tap in this discussion.

As new levels of sophistication are introduced in the CATV industry, the tap can become an active system component and may, in addition to its normal functions, provide disconnect and reconnect capability and channel exclusion functions. In some systems, not only can the tap be individually addressed from, and respond to, the system head end, it may actually perform some signal de-scrambling functions as well.

It is convenient to classify subscriber terminal equipment as standard and optional. By *standard* we mean those items, usually passive in nature, with which every subscriber terminal must be equipped. The *optional* classification covers an almost infinite variety of equipments and features, some of which are still embryonic and have not become standardized as yet.

It is difficult to be precise or authoritative in this area. Many of the alternatives are business management options rather than technical matters, and we may well see new functions and services evolve. Of necessity then we will limit this discussion to basic technology rather than specific configurations or features. For example, there are so many variations of signal scrambling that discussing this in our text seems both inappropriate and inadequate.

Standard Station Equipment

The National Electric Code requires that the outer conductor of a coaxial cable be physically *grounded* at the point where the service drop enters the subscriber premises.

This is accomplished by a variety of grounding blocks that provide electrical connection access to the outer conductor but maintain electrical continuity of the inner conductor.

This is a convenient point to transition from outside plant coaxial cable to a more flexible or less obtrusive type of inside wiring coaxial cable.

Splitters and Couplers

An assortment of passive accessories such as splitters, directional couplers, etc., are available for use at the subscribers premises. Such accessories function just as their outdoor counterparts except they do not generally pass AC power. These are used when more than one television receiver must be fed signal or to serve two or more apartments in multiple dwellings.

Matching Transformers

The coaxial cable is an unbalanced line with a 75 ohm characteristic impedance. Many older television receivers are 300 ohm balanced at the RF input (antenna) connection. Thus a matching transformer called a *balun* (balanced-to-unbalanced line) is required at many television receivers. This is a small, passive device which is generally considered dispensable if it develops any irregularities.

Active Subscriber Taps

Most optional equipment is installed inside the subscriber premises but in some systems, some capability is provided out at the cable tap itself. Of course such taps, called *active taps*, do require operating power which is usually drawn from the coaxial cable system itself. There are many variations on these units, but they can be addressed by the system Head End and usually can, at a minimum, permit remote disconnect or reconnect of service. Beyond this, some units can descranble some signals on command, exclude a channel or several channels, and can handle some forms of Pay-per-View service as well.

Such sophistication was off-premises, and was intended to largely defeat unauthorized subscriber services or use, but active taps are by no means universally used within the Cable industry.

FM Coupler

When broadcast frequency-modulated signals are carried on the cable system (88 to 108 MHz) an *FM coupler* is sometimes used to connect the subscriber's FM radio to the cable system.

This is generally a bandpass type of device which excludes the television signals from being presented to the radio receiver, which might otherwise be changed out to a TV receiver later by the subscriber, and upgraded to an unauthorized set served.

A-B Switches

There are some *dual-cable* television systems in service. In these cases the outside distribution cable plant is duplicated in its entirety, including two paralleling coaxial service drops. In effect, the subscriber's television receiver must be switched from system A to system B if it is to have access to all television signals on both cables, cable A and cable B. This is accomplished with a manually operated coaxial switch located at or near each television receiver served.

This is not a splitter, it was passive, and the cable not connected to the receiver is usually terminated in 75 ohms within the switch itself. The idea of a two cable system was to relieve the number of channels carried by any one cable, thus reducing required bandwidth and distortion contribution, and it allowed carrier frequencies to be repeated on both cables, which provided greater channel carriage into the subscribers home.

Exclusion Traps

Often a cable system offers one or several special channels of programming for an additional service fee. These are commonly called *premium* or pay-TV channels. Obviously, since the additional programming is optional, there must be some method of restricting viewer access to these channels if they do not subscribe to them.

One technique inserts a sharply tuned, *band reject* trap into the subscriber service drop. This device attenuates the premium signal or signals such that the television receiver cannot synchronize on the picture information and viewing is impaired or entirely inhibited. Traps may be single-channel devices or broad enough to cover several signals, and since they are passive in nature, they may be located either within the premises or at the cable tap itself.

Exposed to the weather at the tap, traps may drift or change somewhat in rejection capability, and this is an inherent problem with this approach. Such devices must be temperature stable and are often encapsulated during fabrication with foamed material to help.

Block Converters

When any cable system transports more than 12 TV signals, the additional channels will not be on standard broadcast frequencies (Channels 2 through 13) and many home television receivers, particularly older sets, cannot tune them. Some frequency conversion of these signals is necessary.

One technique takes a group of additional channels that are not on standard broadcast frequencies and heterodynes them all against a local oscillator. The resultant signals fall on standard TV frequency assignments (Channels 7 through 13, for example) and thus can be tuned individually by the subscriber television receiver.

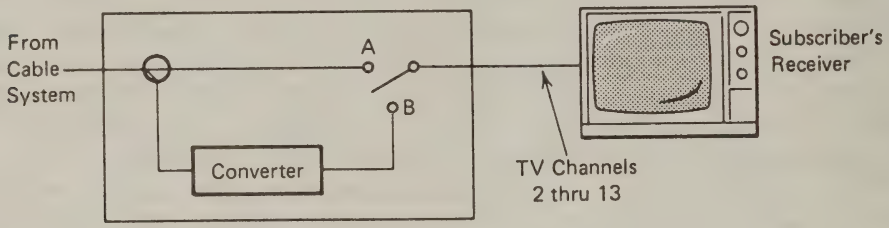


Figure 30-1 Block Converter

Figure 30-1 shows a block diagram of this technique. Block converters require manual switch operation by the viewer. In switch position A, the standard TV signals Channels 2 through 13 that are present on the cable system are passed through the unit and are individually tuned by the subscriber on his TV set. In switch position B, the additional (nonstandard) channels from the cable system are converted to standard channels, and these converted signals are presented to the receiver where they are also individually selected by the subscriber. Block conversion of mid-band or super-band channels or both is available depending on the block converter utilized.

Tunable Converters

A more sophisticated type of converter, and much more commonly employed as well, individually tunes all cable system signals and presents a *single-channel*, standard TV output signal (Channel 3 or 4 for example) that is fed into the subscriber receiver. All channel tuning is done in the converter, and the subscriber receiver stays tuned to the converter output signal all the time.

Variations of this equipment provide converter remote tuning by the viewer from across the room. Tunable converters are available with 20, 35, 52, and other channel capacities.

Figure 30-2 shows a tunable converter with an optional remote tuning head. The basic converter unit is physically located at the subscriber receiver and draws operating power from a subscribers regular wall power outlet. Combinations of two-cable switching and tunable converters are possible.

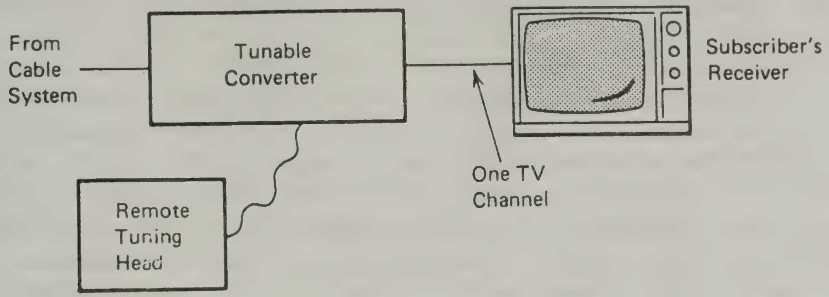


Figure 30-2 Tunable Converter

De-Scrambling

At an extra service charge, premium programs became more common, and second and third *tiers* (levels) of service are presented as options for the customer. The problem of unauthorized viewing of these programs became more severe. The exclusion traps discussed earlier have some merit in that they can be located outside the subscriber's premises, and thus unauthorized use of the excluded signals is more difficult for unscrupulous subscribers. The traps are somewhat limited however, since they perform no other functions.

By scrambling (*encoding*) the video or audio information at the system Head End, the system operator can exclude non-subscribing customers from viewing or using such programs. This requires some un-scrambling (*decoding*) capability in the subscriber terminal equipment however, and this function is most logically provided within the converter itself.

An extension of this logic would provide system operator control of the descrambling capability. If the operator can remotely enable or disable the decoder, he can change service levels at stations without the cost of a visit by personnel. He might also introduce a pay-per-view level of service whereby special programs could be requested by the subscriber. The system operator could enable the decoding function just for that program period for a special billing fee.

The system operator may also be scrambling several signals for several levels of service. By remotely controlling the decoder, a subscriber could be upgraded to receive several premium services or restricted from several programs as necessary, and all of this could be done with no visit to the premises.

Addressability

The more sophisticated operations discussed above require that the system operator be able to individually address each subscriber terminal on demand.

Such capability, called addressability, is coming into more general usage in the CATV industry. Generally a *digitally* encoded special frequency signal is added to the system to provide this control.

A refinement on this capability allows the system operator to entirely disconnect or reconnect the service without a visit to the premises. This could be accomplished either within the converter itself or, if the tap were addressable and active, out at the cable tap off the subscriber premises.

Taps with addressability, disconnect/reconnect, or even de-scramble capability are called *smart taps*. The name comes from comparison with the usual tap which has no such sophistication built into it. Obviously "smart" taps must be powered and will be more expensive than their more prosaic counterparts.

The variety of functions and equipment used to accomplish these operations is much too extensive to cover in this text, but most addressability, in most Cable systems, is accomplished within the subscribers premises and by the station converter itself.

Other Services

Addressability inherently provides the capability for other services. If the system operator can, on demand, select any one station and interrogate it, or command switched functions, it can easily be utilized to interrogate various alarm functions or power or water meter usage readings, etc. There is a line of demarcation between one and two-way services, however. One-way functions such as connect/disconnect, de-scramble authorization, etc., might be quite sufficient for many CATV operations, but many of the other services like alarm systems require response from the subscriber terminal.

When a station can both be addressed and interrogated as well as respond with information or status reports, it is said to be *interactive* In Chapter 17 in our discussion of two-way systems we covered some aspects of two-way, interactive operations and *full talk* capability. The interested reader may wish to review this material.

Feeder Cable Disconnect

There is a function that might be encountered in two-way cable systems that requires addressability, and that is the discriminate disconnection of all return transmission from all feeder cable routes except the one that serves the subscriber terminal that was interrogated. This capability and the advantages of such a function were covered in Chapter 17.

With the advent of hybrid systems and the limitation on coaxial cable amplifiers, this disconnect function has largely become unnecessary, in fact it was not widely used even in all-coaxial systems, but it needed to be technically discussed.

Non-CATV Services

Coaxial cable transmission systems can and do function in special application networks such as Local and Wide Area Networks (LANs and WANs). Although such applications are generally characterized as limited service area, private data and telecommunications systems, they are often required to carry some video signals also. The video application is quite conventional and can be addressed just as the CATV applications we have been discussing throughout this text. For data and other services, most local networks of this type will require two-way transmission capability.

General Discussion

Regardless of what other terminal equipments may be required, each terminal may require a unit that modulates intelligence onto a carrier for transmissions to the system Head End, and demodulates a different carrier to recover intelligence sent to that terminal. Spectrum allocation and separation may be accomplished in a manner similar to that previously discussed in this text with the only unique aspects being different transmission bandwidth requirements than those usually associated with Cable Television service, and perhaps a higher number of signals being transmitted.

Although discussion of these possibilities may be beyond the scope of this text, the transmission system technology is not, and conventional Cable Television hardware and design techniques may be directly applied.

Summary

This text is too limited to permit more detailed discussion of terminal equipments or service capabilities and it is highly probable that innovations, improvements, and new services will be introduced across the next several years. But given some understanding of the basic transmission technology, the reader should be able to handle these changes as they are introduced.

Chapter 31

Construction

For those readers completely unfamiliar with Cable Television we have included this very brief discussion of cable system construction techniques.

Aerial Plant Construction

Aerial plant construction is a technique of suspending the cables from poles to provide overhead clearances. Some mechanical supporting member is required so that the cable itself is not subjected to stress and deformation. Most generally this support is provided through a stranded steel cable which is called a *messenger* or *strand*. It is attached to each pole by a clamp that is bolted to the pole itself, and is pulled to a tension that provides a sag in the span compatible with existing pole line plant such as in-place power or telephone cables.

There are various clearance requirements that dictate the physical separation between different plants, both on the poles themselves and in the spans. The pole structures are generally owned by either the local telephone company or the power distribution company or jointly by both. The Cable operator must enter into a leasing arrangement with the pole line owner which requires that a pole rental fee be paid each year for each pole to which he has attached Cable Television plant.

In addition to the pole rental, the leasing agreement also requires the Cable operator to absorb all plant rearrangement or preparation costs. If adequate or required separation clearances cannot be provided because a pole is either too short, or is too congested with existing plant, then the pole itself may have to be completely replaced which is called a *change out*. In other cases, the telephone cable may simply be raised or lowered on the pole to ensure proper clearance, and the cost of such work, called rearrangement, must also be absorbed by the Cable operator.

Usually the local utility will inspect all poles for proper clearance before the Cable Television construction can proceed. All of these costs including *change outs* and *rearrangements* are called *make ready* charges.

The pole line route and the attached *messenger* must conform to highway and street routes, thus gradual curves or sharp corners must be included. At all points where the plant does not pass a pole in a straight line, a guy wire must be installed.

Usually this involves a *down guy* to a buried anchor to which the guy wire is attached. Anchors and guys are also required where the cable plant ends, and these locations are called *dead ends*.

Once the *messenger* has been strung and pulled to tension, the coaxial or optical cable is pulled in, paralleling and temporarily supported by the messenger itself. Then by use of a lashing machine pulled along the messenger, a lashing wire is spirally wound around both cable or cables and the supporting messenger, creating a single mechanical assembly along the entire cable route.

At locations where equipment must be installed, as well as at intermediate pole locations, the lashing wire is terminated and fastened to the messenger. The coaxial or optical cable is separated from the messenger for a short distance and often an expansion loop is formed in the cable itself. Then the cable lashing process is resumed until the next pole or equipment location is reached.

Self-Supporting Cable Construction

Self-supporting cable uses a similar aerial construction method except that the support member (messenger or strand) is integral with the coaxial or optical cable itself, both being molded into a common polyethylene overjacket. Since only a single placement operation is required to string both cable and messenger, a significant cost reduction in placement is possible. Self-support cable is not very suitable for over lashing a second cable at a later date.

Self-supporting cable has found some limited applications in feeder Cable Television plant, particularly where the plant must be constructed through back yards that may include fences and other obstructions. By pulling both the cable and the supporting messenger through in one work operation and then making all pole attachments and doing splicing operations during a second pass through the section, labor costs may be minimized.

General Discussion (Aerial Plant)

Both aerial construction techniques, self-supporting cable and separate messenger, are similar to the methods used in telephone plant construction. Most generally the CATV cable is located above the telephone cable plant on the pole line, and the top section of the poles is usually reserved for power conductors if there is joint power/telephone usage of the pole line.

With the exception of AC power supplies, CATV equipments and devices are equipped with clamps to attach them directly to the messenger, thus the vertical pole space required is intentionally limited. AC power supplies are too bulky and heavy to be mounted in this manner and are usually bolted directly to the pole itself.

Vertical cable runs are sometimes necessary on poles where an underground cable transitions to aerial construction. The vertical cable run is usually protected in such cases by conduit or molding.

Underground Construction (Trenching)

One method of placing cable underground is to excavate a narrow trench to the desired depth, lay the coaxial or optical cable in the trench, and back-fill. This is a relatively expensive technique and requires a second operation to lay the cable (or cables) into the trench plus a third pass to back-fill and restore the disturbed surface.

Trenching is mandatory, however, if cable ducts are to be placed. These are sectionalized, multi-conduit assemblies placed end-to-end in a trench and then covered with earth. In this manner several conduits can be created between manholes or other points of termination, and cables can be pulled into these conduits, either subsequently or initially.

Underground Construction (Plowing)

Another method for placing cable underground is direct plowing. A powered tractor pulls a plow through the ground and simultaneously feeds the cable (or cables) through the plow shoe. Sometimes the plow is arranged to vibrate or oscillate to create a space below grade for the cable to occupy. Plowing is less expensive, since it creates less surface disturbance and provides the placement of cable in the same work operation of excavation or plowing.

Underground Construction Problems

In either trenched or plowed underground construction the problems of paved streets, driveways, and sidewalks must be addressed. One technique cuts through the pavement, excavates and back-fills, and then restores or replaces the disturbed paving materials. This is quite expensive but sometimes unavoidable.

Another method is to excavate a pit or trench on both sides of the paved area, and then tunnel or bore underneath the paved section. This method is time consuming, but can be much less expensive than the repaving alone.

Mechanical Protection of Plant

Quite obviously, underground plant is less exposed to mechanical damage such as ice storms, trees falling, or poles struck by vehicles, etc. This is offset by a much higher initial plant cost, however. Cables placed underground are subject to moisture ingress, chemical action, and possible rodent damage such as gophers or ground hogs might cause.

Consequently, underground cables require some level of additional protective coating or armor in most cases. Underground cables are usually brought above grade for all installations of amplifiers and other devices. This involves some type of above grade housing such as a pedestal housing, and these introduce additional cost.

Aerial service drops are somewhat vulnerable to ice loads and wind storm damage, and serviced drop cables often include a supporting messenger wire under a molded polyethylene jacket to protect against such damage. Underground service drop cables are usually plowed directly into the ground between the pedestal and the subscriber's premises

Electrical Protection of Plant

Both aerial and underground plant are subject to lightning strikes. Aerial plant is also exposed to contact with other conductors such as power company conductors along the pole line. Physical contact is not the only problem. Longitudinal currents may be induced into the coaxial cable conductors from the power plant itself. With several separate transmission systems utilizing a single pole line (power, telephone, and CATV), differences in potential can be hazardous to servicing personnel.

The CATV cable plant, both the outer conductor and all supporting messenger and hardware, are grounded frequently throughout the system. These grounds and the plant itself are electrically bonded to both power and telephone grounds where possible. Every station service drop must also be grounded and bonded to these other services at the subscriber's premises.

The direct ground connections are to discharge foreign and possibly dangerous voltages and currents as often as possible. Bonding, which connects CATV plant to other grounded plant, is intended to avoid or eliminate differences in the potential of different plants, and thus serves to also protect personnel who may come into contact with both plants inadvertently.

Station Equipments

Where CATV station equipments are entirely passive (not power consuming or requiring any 110 volt AC power connection) the installation is fairly simple and the grounding (through a ground block) of the outer coaxial conductor is considered sufficient.

Where converters or other active devices (requiring connection to the subscriber's 110-volt AC power) are involved, the grounding process is the same but all terminal devices must comply with Underwriter Laboratories (UL) regulations.

Towers and Head End Structures

Tall towers and large antenna arrays at CATV head ends require particular attenuation to grounding and protective procedures, as they are prominent structures and may be more prone to lightning strikes. Protective procedures are the same, however, as those that have been developed and refined over many years for other such towers or structures.

Summary

The subject of plant construction and protection (both mechanical and electrical) is much too broad to cover in this text, but there are reference materials available, and the construction of CATV plant presents no unique or insoluble problems. Almost all construction techniques employed are the same ones commonly used in the telephone business.

Equivalency Tables

Equivalent Values of −dBmV, RMS Voltage, RMS Current, and Power
(at 75 ohms)

dBmV	RMS voltage	RMS current	Power
0	1.00 mV	13.30 uA	13.30 nW
−1	881.00 uV	11.90 uA	10.60 nW
−2	794.00 uV	10.60 uA	8.41 nW
−3	708.00 uV	9.44 uA	6.68 nW
−4	631.00 uV	8.41 uA	5.31 nW
−5	562.00 uV	7.50 uA	4.22 nW
−6	501.00 uV	6.68 uA	3.35 nW
−7	447.00 uV	5.96 uA	2.66 nW
−8	398.00 uV	5.31 uA	2.11 nW
−9	355.00 uV	4.73 uA	1.68 nW
−10	316.00 uV	4.22 uA	1.33 nW
−11	282.00 uV	3.76 uA	1.06 nW
−12	251.00 uV	3.35 uA	841.00 pW
−13	224.00 uV	2.99 uA	668.00 pW
−14	200.00 uV	2.66 uA	531.00 pW
−15	178.00 uV	2.37 uA	422.00 pW
−16	159.00 uV	2.11 uA	335.00 pW
−17	141.00 uV	1.88 uA	266.00 pW
−18	126.00 uV	1.68 uA	211.00 pW
−19	112.00 uV	1.50 uA	168.00 pW
−20	100.00 uV	1.33 uA	133.00 pW
−21	89.10 uV	1.19 uA	106.00 pW
−22	79.40 uV	1.06 uA	84.10 pW
−23	70.80 uV	944.00 nA	66.80 pW
−24	63.10 uV	841.00 nA	53.10 pW
−25	56.20 uV	750.00 nA	42.20 pW
−26	50.10 uV	668.00 nA	33.50 pW
−27	44.70 uV	596.00 nA	26.60 pW
−28	39.80 uV	531.00 nA	21.10 pW
−29	35.50 uV	473.00 nA	16.80 pW
−30	31.60 uV	422.00 nA	13.30 pW

Equivalent Values of −dBmV (*Continued*)

dBmV	RMS voltage	RMS current	Power
−31	28.20 uV	376.00 nA	10.60 pW
−32	25.10 uV	335.00 nA	8.41 pW
−33	22.40 uV	299.00 nA	6.68 pW
−34	20.00 uV	266.00 nA	5.31 pW
−35	17.80 uV	237.00 nA	4.22 pW
−36	15.90 uV	211.00 nA	3.35 pW
−37	14.10 uV	188.00 nA	2.66 pW
−38	12.60 uV	168.00 nA	2.11 pW
−39	11.20 uV	150.00 nA	1.68 pW
−40	10.00 uV	133.00 nA	1.33 pW

Equivalent Values of +dBmV, RMS Voltage, RMS Current, and Power (at 75 ohms)

dBmV	RMS voltage	RMS current	Power
0	1.00 mV	13.30 uA	13.30 nW
+1	1.12 mV	15.00 uA	16.80 nW
+2	1.26 mV	16.80 uA	21.10 nW
+3	1.41 mV	18.80 uA	26.60 nW
+4	1.59 mV	21.10 uA	33.50 nW
+5	1.78 mV	23.70 uA	42.20 nW
+6	2.00 mV	26.60 uA	53.10 nW
+7	2.24 mV	29.90 uA	66.80 nW
+8	2.51 mV	33.50 uA	84.10 nW
+9	2.82 mV	37.60 uA	106.00 nW
+10	3.16 mV	42.20 uA	133.00 nW
+11	3.55 mV	47.30 uA	168.00 nW
+12	3.98 mV	53.10 uA	211.00 nW
+13	4.47 mV	59.60 uA	266.00 nW
+14	5.01 mV	66.80 uA	335.00 nW
+15	5.62 mV	75.00 uA	422.00 nW
+16	6.31 mV	84.10 uA	531.00 nW
+17	7.08 mV	94.40 uA	668.00 nW
+18	7.98 mV	106.00 uA	841.00 nW
+19	8.91 mV	119.00 uA	1.06 uW

Equivalent Values of +dBmV (*Continued*)

dBmV	RMS voltage	RMS current	Power
+20	10.00 mV	133.00 uA	1.33 uW
+21	11.20 mV	150.00 uA	1.68 uW
+22	12.60 mV	168.00 uA	2.11 uW
+23	14.10 mV	188.00 uA	2.66 uW
+24	15.90 mV	211.00 uA	3.35 uW
+25	17.80 mV	237.00 uA	4.22 uW
+26	20.00 mV	266.00 uA	5.31 uW
+27	22.40 mV	299.00 uA	6.68 uW
+28	25.10 mV	335.00 uA	8.41 uW
+29	28.20 mV	376.00 uA	10.60 uW
+30	31.60 mV	422.00 uA	13.30 uW
+31	35.50 mV	473.00 uA	16.80 uW
+32	39.80 mV	531.00 uA	21.10 uW
+33	44.70 mV	596.00 uA	26.60 uW
+34	50.10 mV	668.00 uA	33.50 uW
+35	56.20 mV	750.00 uA	42.20 uW
+36	63.10 mV	841.00 uA	53.10 uW
+37	70.80 mV	944.00 uA	66.80 uW
+38	79.40 mV	1.06 mA	84.10 uW
+39	89.10 mV	1.19 mA	106.00 uW
+40	100.00 mV	1.33 mA	133.00 uW

Units of Measure

uV	(microvolts),	10^{-6} volts
mV	(millivolts),	10^{-3} volts
nA	(nanoamperes),	10^{-9} amperes
uA	(microamperes),	10^{-6} amperes
mA	(milliamperes),	10^{-3} amperes
pW	(picowatts),	10^{-12} watts
nW	(nanowatts),	10^{-9} watts
uW	(microwatts),	10^{-6} watts
mW	(milliwatts),	10^{-3} watts

Formulas

The following symbols were used in the CATV formulas below:

C/N_{amp} = C/N ratio for a single amplifier (dB),
Sig_{in} = input signal level (dBmV),
59 = thermal noise threshold,
NF = manufacturer specified amplifier noise figure (dB),
C/N_{sys} = C/N ratio of cascade (dB),
N = number of amplifiers,
OL_{oper} = operating output signal level (dBmV),
OL_{spec} = manufacturer specified output signal level (dBmV),
XM_{amp} = X-Mod for a single amplifier (dB),
XM_{spec} = manufacturer specified X-Mod for one amplifier (dB),
XM_{sys} = X-Mod of cascade (dB),
C_{equiv} = number of amplifiers in an equivalent cascade.
M = number of return amplifiers in cascade.

To determine the carrier-to-noise (C/N) ratio of a single amplifier when the input signal level and noise figure (NF) are known:

$$C/N_{amp} = Sig_{in} + 59 - NF$$

To determine the input signal level when the amplifier NF is known and the desired C/N ratio is given:

$$Sig_{in} = NF + C/N_{amp} - 59$$

To determine the C/N ratio of a cascade of identical amplifiers when the C/N ratio for a single amplifier is known:

$$C/N_{sys} = C/N_{amp} - 10 \log N$$

To determine the C/N ratio of a single amplifier in a cascade of identical amplifiers when the system (cascade) C/N ratio is known:

$$C/N_{amp} = C/N_{sys} + 10 \log N$$

To determine the input signal level for a cascade of identical amplifiers if the amplifier NF and the desired C/N ratio for the cascade are known:

$$\text{Sig}_{\text{in}} = C/N_{\text{sys}} + NF - 59 + 10 \log N$$

To determine the C/N ratio of a cascade of identical amplifiers if the NF and input signal level are known:

$$C/N_{\text{sys}} = \text{Sig}_{\text{in}} + 59 - NF - 10 \log N$$

To determine the operating output signal level for a single amplifier to produce a specified amount of X-Mod:

$$OL_{\text{oper}} = OL_{\text{spec}} - \left(\frac{XM_{\text{amp}} - XM_{\text{spec}}}{2}\right)$$

To determine the X-Mod for a cascade of identical amplifiers when the operating output signal level is known:

$$XM_{\text{sys}} = XM_{\text{spec}} + 2(OL_{\text{oper}} - OL_{\text{spec}}) + 20 \log N$$

To determine the operating output signal level for a cascade of identical amplifiers when the required X-Mod for the system (cascade) is known:

$$OL_{\text{oper}} = \frac{XM_{\text{sys}} - XM_{\text{spec}} + 2OL_{\text{spec}} - 20 \log N}{2}$$

To determine the X-Mod distortion for a single amplifier if the operating output signal level and amplifier specifications are known:

$$XM_{\text{amp}} = XM_{\text{spec}} + 2(OL_{\text{oper}} - OL_{\text{spec}})$$

To determine the X-Mod distortion for a cascade of identical amplifiers when the X-Mod for a single amplifier is known:

$$XM_{\text{sys}} = XM_{\text{amp}} + 20 \log N$$

To determine the X-Mod acceptable from each amplifier in a cascade of identical amplifiers when the desired X-Mod for the cascade is known:

$$XM_{\text{amp}} = XM_{\text{sys}} - 20 \log N$$

To determine an equivalent amplifier cascade for a two-way system when the return amplifiers in the system include both a known cascade of amplifiers and a known number of total amplifiers:

$$C_{\text{equiv}} = \sqrt{NM}$$

Glossary

- A -

Absorption

In an optical fiber, loss of optical power resulting from conversion of that power into heat.

Absorption losses

Losses caused by impurities, principally transition metals and neighboring elements (Cr, Mn, Fe, Co, Ni), and also by water as well as intrinsic material absorption.

AC Hum Modulation

See hum modulation.

Acceptance angle

Half the vertex angle of that cone within which optical power may be coupled into bound modes of an optical waveguide.

Acceptance cone

A cone whose included angle is equal to twice the acceptance angle.

Active

Containing, or connected to and using, a source of energy.

Aerial cable

Cable suspended in the air on poles or other overhead structures. Usually implies the use of a "messenger strand" to which the cable is lashed for support.

Alternating current (AC)

An electric current which continually varies in amount, and reverses its direction periodically. The plot of current vs. time is usually a sine wave.

AML (Amplitude Modulated Link)

A registered trademark for microwave equipment that is manufactured by Hughes Communications Products Co.

Ampere

Unit of electric current, or rate of flow of electricity. One coulomb per second. One volt impressed across a resistance of one ohm causes a current of one ampere to flow.

Amplification

The act of increasing the amplitude or strength of a signal.

Amplifier

A device that accepts a signal at its input and presents that same signal, without appreciable distortion, but at a higher level amplitude, at its output. CATV amplifiers pass and amplify a relatively wide spectrum.

Amplifier spacing

The spacing in transmission loss, expressed in decibels, between cascaded, or serially connected, amplifiers. Also sometimes used to denote the linear cable distance between amplifiers in a system.

Amplitude modulation

A process whereby the amplitude of a single frequency carrier is varied in accordance with the instantaneous values of a modulating wave.

Analog signal

A signal which is continually variable and not expressed by discrete states of amplitude, frequency, or phase.

Angle of incidence

The angle between an incident ray and the normal to a reflecting or refracting surface.

Angstrom (A)

10^{-10} meters. Its use as a unit of optical wavelength has largely been supplanted in recent years by the nanometer (10^{-9} meter).

Antireflection coating

A single or multiple layer of thin dielectric coating that reduces the reflectivity of an optical surface.

Antenna gain

The ratio, expressed in decibels, of the signal level received or transmitted by an antenna, to the signal level received or transmitted by an isotropic antenna at that same location which is subject to the same power level.

APD

See avalanche photodiode.

Armored cable

A cable having one or two layers of steel tapes or steel wires spirally applied to the sheath to provide mechanical protection.

Asynchronous

Not synchronous.

Attenuation

The decrease in signal strength along a conductor, cable, or optical fiber. In an optical fiber acting as a waveguide, it is caused by absorption and scattering. This parameter is usually measured in decibels per kilometer.

Attenuation-limited operation

The condition prevailing when the received signal amplitude rather than distortion limits performance.

Attenuator

A device or network for reducing the amplitude of a signal without introducing distortion. May be fixed or variable, with the loss introduced expressed in decibels. Often called a pad.

Atmosphere

The gaseous envelope surrounding the Earth, composed of 78% nitrogen, 21% oxygen, 0.9% argon, plus some carbon dioxide and water vapor. The atmosphere is divided into several layers, as follows:

Troposphere	0-10 miles
Stratosphere	10-50 miles
Ionosphere	50-370 miles
Exosphere	370 + miles

Automatic gain control (AGC)

A feature of some amplifiers and radio receivers which provides a substantially constant output even though the signal input varies over wide limits.

Automatic level control (ALC)

See Automatic gain control.

Automatic slope control (ASC)

A circuit that controls the slope of an amplifier automatically. See Slope.

Avalanche effect

The cumulative multiplication of carriers in a semiconductor caused by an electric field across the barrier region strong enough so that electrons collide with valence electrons, releasing new electrons which have more collisions, which release more electrons, etc.

Avalanche photodiode (APD)

A photodiode designed to take advantage of avalanche multiplication of photo-current. As the reverse-bias voltage approaches the breakdown voltage, hole-electron pairs created by absorbed photons acquire sufficient energy to create additional hole-electron pairs when they collide with substrate atoms; thus a multiplication effect is achieved. Amplification is almost noiseless, and this makes APD's 10 to 15 dB more sensitive than PIN photodiodes. The problems with APD's are: temperature sensitivity, high reverse bias voltages (200 to 400 V to achieve current multiplication of 100), and prices higher than PIN photodiodes.

Axial mode

See longitudinal mode.

Axial ray

A ray passing through the axis of the optical waveguide without any internal reflection.

- B -

Backscattering

The scattering of light in a direction generally reverse to the original one.

Bandwidth

1. A range of frequencies (a portion of spectrum) defined by upper and lower frequency limits.
2. The capacity of an optical fiber to transmit information expressed in bits of information transmitted in a specific time period for a specific length of optical waveguide. Usually expressed like 10 megabits/sec/km. Bandwidth is limited by pulse spreading or broadening due to dispersion, so that adjacent pulses overlap and cannot be distinguished.
3. The range of frequencies within which a fiber optic waveguide or terminal device performs at a given specification.

Bandwidth-limited operation

The condition prevailing when the system bandwidth, rather than the amplitude (or power) of the signal, limits performance. The condition is reached when the system distorts the shape of the wave form beyond specified limits. For linear systems, bandwidth-limited operation is equivalent to distortion-limited operation.

Beam splitter

A device that divides an incident beam into two or more separate beams. Prisms, thin films, sheets of glass, and partially silvered mirrors can be used to split a beam.

Beat

1. To combine two carriers, so as to produce new sum and difference frequency carriers.
2. A carrier generated by two or more carriers which have been passed through a non-linear circuit.

Bel

The fundamental division of a logarithmic scale for expressing the ratio of two powers, which are in the ratio of one to ten. The Bel is an awkwardly large unit, so the "decibel" (one-tenth of a Bel) is used instead.

BER

Acronym for bit error rate.

Bi-directional

Having equal effectiveness in two directions which are separated by 180 degrees in azimuth.

Bi-directional transmission

Signal transmission in both directions along an optical waveguide or other transmission medium.

Binary

Having two possible states or values.

Binary digit

One unit of information in binary (two-level) notation.

Binary state

Either of the two conditions of a bi-stable device, the "one" state or the "zero" state.

Bipolar signal

A type of direct current signal in which consecutive marks are of opposite polarity, and a space is represented by zero voltage.

Bit

1. An electrical or light pulse whose presence or absence indicates data. The capacity of the optical waveguide to transmit information through the waveguide without error is expressed in bits per second per unit length.
2. An acronym for "binary digit."

Bit-error rate

In a digital communications system, the fraction of bits transmitted that are received incorrectly. If BER is specified at 10^{-9} (a typical value), then an average of one bit per one billion sent will be read wrong by the receiver.

Bit rate

The speed at which digital information is transmitted, usually expressed in bits per second.

Bridger amplifier

An amplifier introduced into a system to transition from low transmission levels in the trunk sub-system, to higher transmission levels in the feeder sub-system, of a trunk plus feeder designed CATV system. Also used to provide signal feed points to feeder cables from trunk cables.

Brightness

An attribute of visual perception in accordance with which a source appears to emit more or less light; since the eye is not equally sensitive to all colors, brightness cannot be a quantitative measure.

Buffer

1. A device used as an interface between two circuits or pieces of equipment to reconcile their incompatibilities or to prevent variations in one from affecting the other.
2. A circuit used for transferring data from one unit to another when temporary storage is required because of different operating speeds or times of occurrence of events.

Buffer Tube

An element that may be used to protect an optical fiber waveguide from physical damage, providing mechanical isolation and protection.

Buried cable

A cable installed directly in the earth without the use of underground conduits.

- C -

Cabling

1. The act of twisting together two or more wires, pairs, or pair groups by machine to form a cable.
2. The act of installing distribution cable, particularly in a new area.

Cable loss

The reduction in signal level introduced by passing the signal (or signals) through a length of cable, expressed in decibels.

Carrier

A sinusoidal current which can be modulated with intelligence for communications purposes.

Carrier-to-noise ratio (C/N ratio)

The difference in amplitude of a carrier, and the noise power that is present in that portion of spectrum occupied by the carrier. See Noise.

Cascade

Any number of amplifiers or devices connected in tandem, or serially, such that the output of one is connected to the input of another, etc.

Carrier frequency

1. The frequency of an un-modulated carrier wave.
2. Any of the frequencies which are suitable for use as carriers.

Carrier system

A method of transmitting electrical intelligence by modulating it onto a higher frequency carrier wave, and then, at the receiving end, recovering the original intelligence by the reverse process of demodulation. Useful because many channels of intelligence can be modulated on one carrier wave on a single transmission channel.

Carrier transmission

A means of transmitting information electrically in which the transmitted wave is a wave resulting from the modulation of a single-frequency sinusoidal wave by a complex modulating wave.

Carrier wave

The sinusoidal single-frequency wave which is modulated by a complex intelligence wave (called the modulating wave) to obtain a modulated wave capable of carrying much intelligence over a single channel.

Cavity

The volume (resonator) which provides feedback for laser oscillations. The most common configuration consists of an active medium between two plane or curved mirrors, called cavity mirrors or end mirrors.

Circuit reliability

The percentage of time a circuit was available to the user during a specified period of time.

Cladding

The low refractive index material which surrounds the core of the fiber and protects against surface contaminant scattering. In all-glass fibers the cladding is glass. In plastic-clad silica fibers, the plastic cladding also may serve as the coating.

Coaxial cable

Two metallic conductors, separated by a dielectric material, which share the same axis.

Collimation

The process by which a divergent or convergent beam of radiation is converted into a beam with the minimum divergence possible for that system (ideally, a parallel bundle of rays).

Composite triple beat (CTB)

Spurious carriers that are generated by the sum and difference products of any three carriers present, as many carriers are passed through a nonlinear circuit or device. Composite triple beat is calculated as a voltage addition.

Conduit

A pipe or tube, of tile, asbestos-cement, plastic or steel, which is placed underground to form ducts through which cables can be passed.

Connector

A reusable device for making temporary junctions between two optical fibers.

Converter

A circuit or device that changes the frequency of a carrier by heterodyning it against a locally generated carrier. See Heterodyne.

Converter, set top

See Converter, subscribers.

Converter, subscribers

A unit or device that changes the frequency of carriers delivered at a subscriber's premises from a CATV system, to a carrier (or carriers) that can be tuned, detected, and displayed by conventional television receivers at the subscriber's premises.

Core

The light conducting portion of an optical waveguide. It is composed of a high refractive index material made typically of silicon tetrachloride (SiC14). The addition of germanium tetrachloride (GeC14) increases the refractive index of the core and creates an index gradient along a waveguide.

Core diameter

The diameter of the circle that circumscribes the core area.

Couplers

In fiber optics, a device which links three or more fibers, providing two or more paths for the transmission signal. In an "active"coupler, a switching mechanism selects among several routes; in a "passive" coupler, routing is determined by the geometry of the device.

Cross-modulation (X-Mod)

Modulation (intelligence or information) that is superimposed onto a different modulated or un-modulated carrier, from another modulated carrier that is present, when both signals are passed through a nonlinear circuit.

Cycle

One complete sequence of values of an alternating wave starting at zero, increasing to a maximum positive value, decreasing to zero, increasing to a maximum negative value, and decreasing to zero again. Also called a Hertz.

- D -

Decibel (dB)

1. A logarithmic unit of measure expressing the ratio of two discrete levels, input and output for example, of power, voltage, or current. May be used to denote either loss

(-dB) or gain (+dB). One cannot denote an input or output signal level in dB, but one can denote gain or loss in dB. 2. The standard unit used to express gain or loss of power.

Decibel-millivolts (dBmV)

A logarithmic unit of measure of absolute power, voltage, or current. The dB denotes a ratio between two levels (see Decibel) but the qualifying term mV establishes one of the levels as a reference. Zero dBmV (0 dBmV) is one millivolt (0.001 or 10^{-3} volts) measured across a 75 ohm impedance. Since the impedance is specified and fixed (75 ohms), 0 dBmV is also a reference power level of 0.0133 microwatts. One cannot denote cable loss or amplifier gain in dBmV, but one can denote input or output signal levels in dBmV.

Decibel-milliwatt (dBm)

A unit of power. Decibels referenced to a unit of one milliwatt. Zero dbM = 1 mW.

Decibel-Watt (dBW)

A unit of power. Decibels referred to a unit of one watt. Zero dBW = 1 Watt.

Detect

To rectify a modulated carrier wave and thereby recover the original modulating wave.

Detection

The process by which a wave corresponding to the modulating wave is obtained from a modulated wave.

Dielectric

A nonconducting (insulating) material, such as glass.

Digital signal

A signal which is expressed by discrete states. For example, the absence or presence of a voltage, the level of amplitude of a voltage, the duration of the presence of a voltage, etc. Information or intelligence to be transported may be assigned value or meaning by combinations of the discrete states of the signal using a code of pulses or digits.

Directional coupler

A network or device that diverts a predetermined amount of its input signal to one of two outputs, with the remaining balance of the input energy being presented to a second output.

Dichroic filter

An optical filter designed to transmit light selectively according to wavelength (most often, a high-pass or low-pass filter.

Dichroic mirror

A mirror designed to reflect light selectively according to wavelength.

Diffraction

The deviation of light rays from the paths predicted by geometrical optics.

Diffraction grating

An array of fine, parallel, equally spaced reflecting or transmitting lines that mutually enhance the effects of diffraction to concentrate the diffracted light in a few directions determined by the spacing of the lines and the wavelength of the light.

Digital

Referring to the use of digits to formulate and solve problems, or to encode information.

Digital data

Any data which is expressed in digits. Usually implies the use of binary digits.

Digital signal

A signal which is expressed by discrete states. For example, the absence or presence of a voltage, the level of amplitude of a voltage, the duration of the presence of a voltage, etc. Information or intelligence to be transported may be assigned value or meaning by combinations of the discrete states of the signal using a code of pulses or digits.

Dispersion

A term used to describe the chromatic or wavelength dependence of a parameter as opposed to the temporal dependence which is referred to as distortion. The term is used, for example, to describe the process by which an electromagnetic signal is distorted because the various wavelength components of that signal have different propagation characteristics.

Double window

An optical fiber having desirable transmittance characteristics in both the first and second window regions.

Dynamic range

In a transmission system, the difference in decibels between the noise level of the system and its overload level.

- E -

Echo

Reflected energy confined to only a portion of the spectrum which is occupied by the originating signal.

Electronic

Describing devices which depend upon the flow of electrons in vacuum or in semiconductors, such as electron tubes, transistors, etc.

Electron volt

The amount of energy gained by one electron in passing from a point to another point which is one volt higher in potential.

Electromagnetic Wave

A wave capable of propagating energy through space at the speed of light, consisting of electric and magnetic fields at right angles to each other and to the direction of propagation. Depending upon its frequency it may be known as a radio wave, a light wave, or an x-ray, etc.

Equalize

To apply to a transmission facility a network, whose characteristics are complementary, such that the loss or delay in the facility and in the equalizing network combined, make the overall loss or delay almost the same for all frequencies passed through the facility or network.

Equalizer

A network designed to compensate for an undesired frequency or delay characteristic of a system or a device.

Equalizer, cable

A network designed to compensate for the frequency/loss characteristics of a cable, so as to permit the system to pass all frequencies in a uniform manner.

- F -

Feeder

A sub-system within a trunk plus feeder designed CATV system, which provides complete distribution of signals to subscribers within a limited section of the CATV service area.

FET photodetector

A photodetector employing photo-generation of carriers in the channel region of a Field Effect Transistor structure to provide photo-detection with current gain.

Fiber buffer

A material and element that may be used to protect an optical fiber waveguide from physical damage, providing mechanical isolation and/or protection.

Fiber-optic link

Any optical transmission channel designed to connect two end terminals or to be connected in series with other channels.

Field strength meter (FSM)

See Signal level meter.

Filter

A network which is frequency sensitive, in that it passes readily or attenuates, specific frequencies or bands of frequencies.

Free space loss

The transmission loss between two isotropic radio antennas, ignoring variable factors, and dependent only on distance and frequency.

Frequency

For a periodic wave such as an alternating current, the number of complete cycles per some unit of time, generally referenced to one second. See Cycle.

Frequency Division Multiplexing (FDM)

Frequency division is a method for multiplexing several *carriers on a transmission system by assigning a different* frequency to each, *thus each separate carrier can be* recovered by tuning. In optical communications, one also encounters wavelength division multiplex (WDM) which involves the use of several distinct optical sources, each having a distinct center lightwave frequency.

Frequency modulation (FM)

A process whereby the frequency of a single frequency carrier is varied in accordance with the instantaneous value of a modulating wave.

Frequency response

The transmission loss or gain of a system, device, or network measured across the transmission bandwidth presented, as compared with the loss or gain at some reference frequency within the bandwidth.

Fusion splice

A splice accomplished by the application of localized heat sufficient to fuse or melt the ends of two lengths of optical fiber, forming a continuous, single fiber.

Fusion splicer

An instrument which permanently joins two optical fibers by welding their cores together with a brief electric arc.

- G -

Gain

An increase in power produced by an amplifier and expressed in decibels. See Amplifier.

Gain module

A mechanical sub-assembly within an amplifier housing which produces gain.

Gain, usable

The gain presented for use between the input and output connections of an amplifier housing. Since several accessory items may be included inside the housing, but external to the gain module, such as pads, equalizers, two-way filters, etc., the gain provided by the gain module itself will generally be somewhat higher than the usable gain actually available between the housing cable connections.

Gallium aluminum arsenide (GaA1As)

The compound used to make most semiconductor lasers that operate at 800 to 900 nanometers in wavelength.

Giga

A prefix used to represent one billion or 10^9 or 1,000,000,000; abbreviated as G as in GHz, one billion cycles (Hertz) per second.

Gigacycle (Gc)

See Gigahertz.

Gigahertz (GHz)

One billion hertz. One billion cycles per second. See Hertz and Cycle.

Graded index fiber

An optical fiber which has a refractive index that gets progressively lower away from the center. This characteristic causes the light rays to be continually refocussed by refraction in the core. A fiber type wherein the core refractive index decreases almost parabolically radially outward toward the cladding. This type of fiber combines high-bandwidth capacity with moderately high coupling efficiency.

Guard band

A portion of spectrum left vacant and not utilized between two carriers or bands of carriers, to provide a margin of safety against mutual interference.

Guided wave

A wave which is concentrated between materials having different properties, and is propagated within those boundaries.

- H -

Hertz (Hz)

Frequency of periodic oscillations, expressed in cycles per second.

Heterodyne

1. Combining two carriers to generate a new carrier which may be either the sum or difference addition of the original frequencies.
2. To shift a carrier frequency to a new frequency by combining it with another carrier which is locally generated.

Heterodyne signal processor

A unit employed in CATV systems to convert a carrier frequency to an intermediate frequency (IF). The intermediate frequency carrier may then be filtered, regulated, or otherwise conditioned, and then heterodyned back to either the original carrier frequency, or to a completely new carrier frequency.

High band

The radio spectrum between 174 and 216 megahertz (MHz). Standard television channels 7 through 13 fall within this spectrum.

Horsepower

A unit of mechanical power equivalent to 550 foot-pounds per second, or to 745.7 Watts.

Hum modulation

Undesired low frequency modulation of a carrier at the frequency of the source of the interference, or a harmonic of that frequency, usually 60 Hz or 120 Hz, for example.

Hybrid System

In Cable Television systems, this refers to a system that incorporates lightwave transmission on optical fibers for a part of the system, and extends the plant on RF broadband coaxial cables for distribution and connection to subscribers.

Hydroxylion absorption

Absorption of optical power in optical fiber due to hydroxyl (OH) ions. This absorption has to be minimized for low fiber loss.

- I -

Index matching material

A material, often a liquid or cement, whose refractive index is nearly equal to an optical element index. Material with an index nearly equal to that of an optical fiber's core is used in splicing and coupling to reduce reflections from the fiber end face.

Index profile

A characteristic of an optical fiber which describes the way its index of refraction changes with its radius.

Insertion loss

The loss introduced into a cable or system by the insertion of a device or network expressed in decibels. See Loss.

Interference

Noise or other disturbances such as spurious signals that, when introduced to a desired signal, reduce the intelligibility of the information carried on that signal.

Intermodulation distortion

The distortion introduced when several or many carriers are passed through a nonlinear circuit. This includes the spurious signals (beats) produced as sum and difference additions of the carriers present, and the transfer or superimposition of modulating information from one carrier to another.

Infrared

Electromagnetic radiation with wavelength between 0.7 micrometer and about 1 millimeter. Wavelengths at the shorter end of this range are frequently called "near" infrared, and those longer than about 20 micrometers, "far" infrared.

Intrinsic noise

See Noise, intrinsic.

- J -

Jacket

A layer of material, generally plastic, that surrounds an optical fiber to protect it from physical damage. Unlike the cladding, the jacket is physically distinct from the fiber core.

Joule

An international unit of work or energy. The work required to maintain a current of one ampere through one ohm for one second. A Watt-second.

- K -

Kilo-

A prefix for one thousand (1,000 or 10^3).

Kilobit

One thousand bits.

Kilocycle (Kc)

See Kilohertz.

Kilohertz (kHz)

1. One thousand hertz.
2. One thousand cycles per second.

- L -

Laser

Acronym for "light amplification by stimulated emission of radiation." A device which generates or amplifies electromagnetic oscillations at wavelengths between the far infrared (sub-millimeter) and ultraviolet. Like any electromagnetic oscillator, a laser oscillator consists of two basic elements: an amplifying (active) medium and a regeneration or feedback device (resonant cavity). A laser's amplifying medium can be a gas, semiconductor, dye solution, etc. Feedback is typically from two mirrors. Distinctive properties of the electromagnetic oscillations produced include monochromaticity, high intensity, small beam divergence, and phase coherence. As a description of a device, "laser" refers to the active medium plus all equipment necessary to produce the effect called lasing.

Lashed cable

An aerial cable fastened to its supporting messenger by a continuous spirally wrapped steel wire.

Light Emitting Diode (LED)

Acronym for light emitting diode.

Lightguide

Synonym for optical waveguide.

Light source

A generic term that includes lasers and LED's.

Lightwave

Any electromagnetic radiation having a wavelength in the range from 800 to 1,600 nanometers in the near infrared region.

Linear

The characteristic of a device or network whose output signal voltage is directly proportional to its input signal voltage.

Line extender

An unsophisticated amplifier operating at relatively high transmission levels in the feeder sub-system of a trunk plus feeder designed CATV system.

Long wavelength

As applied to fiber optic systems, this term generally refers to operation at wavelengths in the range of 1,100 nanometers to 1,700 nanometers.

Low band

The radio spectrum between 54 and 88 MHz. Standard VHF television channels 2 through 6 fall within this spectrum.

Loss

Power dissipated in a device, cable, or network expressed in decibels. See attenuation.

- M -

Mechanical splice

A fiber splice accomplished by fixtures or materials, rather than by thermal fusion. Index matching material may be applied between the two fiber ends.

Mega-

A prefix for one million (1,000,000 or 10^6).

Megabit (mb)

One million bits.

Megacycle (mc)

See Megahertz.

Megahertz (mHz)

One million hertz. One million cycles per second. See Hertz and Cycle.

Micro-

A prefix for one millionth (10^{-6}).

Micron

The unit used for specifying the wavelength of light, equal to one millionth of a meter.

Microwave

A term denoting radio waves which are in the electromagnetic spectrum at frequencies approximately 1,000 MHz and higher.

Mid-band

The radio spectrum between 88 and 174 MHz which lies between standard VHF television channels 6 and 7. CATV channels A through I (nine channels) fall within the mid-band spectrum.

Milli-

A prefix for one thousandth (10^{-3}).

Milliwatt

One thousandth of a Watt.

Mode field diameter

A functional representation of the energy carrying region of the fiber. Also referred to as Spot size.

Modem

A single unit of equipment which combines the functions of modulator and demodulator. This is an economical arrangement, since the two circuits can use common elements.

Modulation

The process by which some characteristic of a wave such as amplitude, frequency, or phase is varied in accordance with a modulating wave. This term is also commonly used to refer to the information (intelligence) present on a modulated carrier.

Monochromatic

Consisting of a single wavelength or color. In practice, radiation is never perfectly monochromatic but, at best, displays a narrow band of wavelengths.

Monomode optical waveguide

Synonym for single mode optical waveguide.

Multimode

Emission at several frequencies simultaneously, generally closely spaced, each frequency representing a different mode of laser oscillation in the resonant cavity. A term that describes optical waveguide that permits the propagation of more than one mode.

Multimode fiber

A fiber that supports propagation of more than one mode of a given wavelength.

Multiplexer

A device which combines two or more optical signals onto one communications channel. The signals can be of different wavelengths (wavelength-division multiplexing) or can occupy different time slots (time-division multiplexing).

Combination of information signals from several channels into one single optical channel for transmission.

- N -

NA

Abbreviation for Numerical aperture.

Nano-

A prefix meaning "one-thousandth of a millionth." One billionth (10^{-9}).

Nanosecond

One billionth of a second.

Noise

1. Any random disturbance in a communication system which tends to obscure the clarity and validity of a signal in relation to its intended end use.
2. Any signal having random fluctuations and frequency components.
3. An unwanted signal in a communication system, though if not random it should be called "interference."

Noise, intrinsic

Noise which is normally present in a transmission path or device which is not caused by modulation and which is not affected by input level or system loading.

Noise, thermal

Noise produced by the random motion of free electrons in all electrical conductors. The movement of an electrical charge (electron) through the resistance of the conductor produces a (noise) voltage. Thermal noise is white noise.

Noise, white

A noise whose power per unit of frequency is essentially independent of frequency over a specified frequency range. It is therefore a broadband noise having constant energy per hertz, per 100 hertz, etc. Its amplitude-frequency curve slopes upward at 3 dB per octave.

Numerical aperture (NA)

Measure of light acceptance of an optical waveguide.

- O -

Off-air signals

Signals received on an antenna after propagation through space from a broadcasting antenna. Usually refers to signals transmitted by licensed public broadcasting stations.

Optical axis

The axis of symmetry of an optical system.

Optical cable

A fiber, multiple fibers, or fiber bundle in a structure fabricated to meet optical, mechanical, and environmental specifications.

Optical detector

A transducer that generates an output electrical signal when irradiated with optical power.

Optical fiber

Any filament or fiber, made of dielectric materials, that guides light, whether or not it is used to transmit signals.

Optical link

Any optical transmission channel designed to connect two end terminals or to be connected in series with other channels.

Optical power

Colloquial synonym for radiant power.

Optical spectrum

Generally, the electromagnetic spectrum within the wavelength region extending from the vacuum ultraviolet at 40 nm to the far infrared at 1 mm.

Optical time-domain reflectometer

An instrument which locates faults in an optical fiber by sending a short pulse of light through the fiber, then timing the arrival of backscattered signals which originate at discontinuities in the fiber.

Opto-electronic

Pertaining to a device that responds to optical power, emits or modifies optical radiation, or utilizes optical radiation for its internal operation. Any device that functions as an electrical-to-optical or optical-to-electrical transducer.

Note: Photodiodes, LED's, injection lasers and integrated optical elements are examples of opto-electronic devices commonly used in optical waveguide communications.

Oscillator

A circuit generating an alternating current wave at some specific frequency.

Output capability

Defines the relationship between the intermodulation distortion introduced, and the operating output signal levels of an amplifier, with the traffic loading of the device as a factor.

Output power

Radiant power, expressed in Watts.

- P -

Pad

See Attenuator.

Paired cable

Cable in which the conductors are combined in pairs, i.e.: two wires which are twisted about each other. Each wire of the pair has its distinctive color of insulation.

Passive

Describing a device which does not contribute energy to the signal it passes.

Phase lock

The control of an oscillator such that its output signal maintains a constant phase angle relative to a second, reference signal.

Photodetector

Any device which detects light, generally producing an electronic signal with intensity proportional to that of the incident light.

Photodiode

A diode designed to produce photo-current by absorbing light. Photodiodes are used for the detection of optical power and for the conversion of optical power to electrical power.

Photon

A quantum of electromagnetic energy.

Pico-

A prefix denoting one millionth of a millionth; one trillionth (10^{-12}). Pronounced "pie-ko."

Pigtail

A short length of optical fiber, permanently fixed to a component, used to couple lightwave power between it and the transmission fiber.

PIN photodiode

A diode with a large intrinsic region sandwiched between p-doped and n-doped semiconducting regions. Photons absorbed in this region create electron-hole pairs that are then separated by an electric field, thus generating an electric current in a load circuit.

Plant

A general term applied to any of the physical property of a service company which contributes to the furnishing of power or communication services.

Power

Energy per unit of time.

Pulse broadening

An increase in pulse duration. Note: Pulse broadening may be specified by the impulse response, the root-mean-square pulse broadening, or the full-duration-half-maximum pulse broadening.

Pulse decay time

The time required for the instantaneous amplitude of an electrical wave to go from 90% to 10% of the peak amplitude.

Pulse length

The time duration of the burst of energy emitted by a pulsed laser; also called pulse width. Usually measured at the "half-power" points (0.707 times the full height of a voltage or current pulse).

Pulse rise time

The time required for the instantaneous amplitude of an electrical wave to go from 10% to 90% of the peak amplitude.

- Q -

- R -

Radiant energy

Energy (joules) which is transferred via electromagnetic waves; there is no associated transfer of matter.

Ray

A geometric representation of a light path through an optical device: a line normal to the wave front indicating the direction of radiant energy flow.

Rayleigh scattering

Scattering of a lightwave propagating in a material medium due to the atomic or molecular structure of the material and variations in the structure as a function of distance. The scattering losses vary as the reciprocal of the fourth power of the wavelength. The distances between scattering centers are small compared to the wavelength. Rayleigh scattering is the fundamental limit of fiber loss in the operating wavelength region (0.8-1.6 um) of optical fiber systems.

Ratio

The relative size of two quantities indicated by the quotient obtained by dividing one quantity by the other.

Receiver

A unit including a detector and signal-processing electronics that converts optical input into electronic output; often used in communications.

Reflection

1. Reflected energy which substantially covers the spectrum occupied by the originating signal.

2. The abrupt change in direction of a light beam at an interface between two dissimilar media so that the light beam returns into the medium from which it originated.

Refraction

The bending of a beam of light at an interface between two dissimilar media or in a medium whose refractive index is a continuous function of position (graded-index medium).

Refractive index

The ratio of the velocity of light in a vacuum to the velocity of light in the specified medium.

Repeater

A signal amplification device, often used along cables to extend transmission distances.

Response

The fidelity with which the output of a system, device, or network corresponds to its input.

Responsivity

The ratio of an optical detector's electrical output to its optical input, the precise definition depending on the detector type; generally expressed in Amperes per Watt or Volts per Watt of incident radiant power.

Return loss

1. A term for reflection coefficient or voltage standing wave ratio (VSWR). Return loss is the reflection coefficient expressed in decibels.
2. A measure of the dissimilarity between two impedances.

Return loss, structural

The return loss of coaxial cable as established by discrete discontinuities introduced during the manufacturing process.

Ribbon cable

A cable whose conductors lie side by side in a single plane. Usually has a molded polyethylene insulation.

Rise time

For an emitter, the time it takes for light intensity to rise from 10% to 90% of peak output. Detector rise time, also called response time, is the time in which the detector output goes from 10% to 90% of peak.

- S -

Second-order distortion

Spurious signals generated when two or more carriers are passed through a nonlinear circuit. The spurious signals are sum and difference products of any two carriers. Sometimes referred to as second-order "beats." Second order distortion is calculated as a power addition.

Second Window

Characteristic of an optical fiber having a region of relatively high transmittance surrounded by regions of low transmittance in the wavelength range of 1200 to 1350 nanometers.

Semiconductor

A material whose resistivity is between that of conductors and insulators, and whose resistivity can sometimes be changed by light, an electric field, or a magnetic field. Current flow is sometimes by movement of negative electrons, and sometimes by transfer of positive holes. Used in transistors, diodes, photodiodes, photocells, and thermistors. Some examples are: silicon, germanium, selenium, and lead sulfide.

Semiconductor, n-type

A semiconductor material, such as germanium or silicon, which has a small amount of impurity, such as antimony, arsenic, or phosphorous added to increase the supply of free electrons. Such a material conducts electricity through movement of electrons.

Semiconductor, p-type

A semiconductor material which has been doped so that it has a net deficiency of free electrons. It therefore conducts electricity through movement of "holes," which see.

Sensitivity

Imprecise synonym for responsivity. In optical system receivers, the minimum power required to achieve a specified quality of performance in terms of output signal-to-noise ratio or other measure.

Scattering

The change in direction of light rays or photons after striking a small particle or particles. It may also be regarded as the diffusion of a light beam caused by the inhomogeneity of the transmitting medium.

Signal level meter (SLM)

A tuned radio frequency voltmeter, usually calibrated in decibels per millivolt (dBmV) as well as voltage.

Signal-to-noise ratio (S/N ratio)

The difference in amplitude of a signal (before modulation or after detection of a modulated carrier), and the noise present in the spectrum occupied by the signal, when both are measured at the same point in the system.

Single-cable design

A technique for designing CATV systems that utilizes a single type of amplifier with identical transmission levels throughout the system. It may, or may not, actually require some placement of paralleling cables in portions of the system.

Single-mode fiber

An optical waveguide through which only one mode will propagate. Single-mode waveguide is produced by reducing the diameter of the core of the waveguide to 2 to 10 microns. The diameter of the core is dependent on the difference in the refractive index of the core and cladding. As the difference in the refractive index of the core and cladding decreases, the diameter of the core increases. Theoretically, the core could be infinitely large as the difference in index become infinitely small. Single-mode operation is desirable because all modes except the lowest and simplest mode are excluded. This reduces time distortion of signals propagating in unwanted modes, retains phase relationships, and reduces dispersion to the lowest possible value.

Slope

The variation in gain at different frequencies introduced by an amplifier across the spectrum passed by the amplifier.

SNR

Acronym for signal-to-noise ratio.

Source

A device that, when properly driven (with electrical energy), will produce information-carrying optical signals.

Spectrum

A range of frequencies within which waves have common characteristics. For example, audio spectrum, radio spectrum, etc. Radio spectrum is generally accepted to include the range between 8 KHz and 300 GHz.

Splice

A permanent connection of two optical fibers.

Splitter

A network or device that divides its input energy equally between two outputs. It is possible to cascade (serially connect) splitters to provide more than two outputs, but usually the input energy is not then equally divided across those outputs if the outputs are not multiples of two.

Star coupler

A passive device in which power from one or several input waveguides is distributed amongst a larger number of output optical waveguides.

Step-index fiber

A type of fiber which has an abrupt change in index of refraction at the core/cladding interface. Generally such fibers have larger cores, higher losses, and lower bandwidths than graded-index types.

Step-index profile

A refractive index profile characterized by a uniform refractive index within the core and a sharp decrease in refractive index at the core-cladding interface.

Sub-band

The radio spectrum between 5 and 54 MHz.

Subscriber converter

See Converter, subscriber.

Subscriber's loop

Circuit between a local office and a subscriber's telephone set.

Super-band

The radio spectrum between 216 and approximately 400 MHz.

Super-trunk

A sub-system cable transmission link for transporting television signals between two discrete locations.

Sync pulse

Information included in a composite video signal to synchronize the television receiver's picture tube electron beam with the electron beam in the television camera which originated the video signal, or with any other source of a video signal.

- T -

Tap, subscriber

A device that diverts a predetermined amount of its input energy to one or more tap outputs for the purpose of feeding energy into subscriber service drop cables. The remaining balance of the input energy is presented to a tap output port for propagation farther out into the system.

Tap, optical

A device for extracting a portion of the optical signal from a fiber.

Termination

An electrical load connected to a cable, device, or network, to terminate the unit in a specific manner. Generally a termination will have the same impedance as the unit to which it is connected.

Tensile strength

The maximum stress that a material subjected to a stretching load can withstand without permanent damage. This is a common way of specifying the strength of optical fibers and cables.

Terahertz (THz)

10^{12} Hz

Thermoelectric cooling

A method of cooling in which an electric current is passed through two dissimilar metals joined at two points; heat is liberated at one junction and absorbed at the other junction (the process is the reverse of that in a thermocouple detector). In a thermoelectric refrigerator, the cold (heat-absorbing) junction is thermally coupled to the device to be cooled.

Tilt

The variation in amplitude for different frequencies at various points within a system. Predominantly introduced by coaxial cable, which does not introduce the same attenuation to all frequencies passed.

Total internal reflection

The total reflection that occurs when light strikes an interface at angles of incidence (with respect to the normal) greater than the critical angle.

Transducer

A device which receives a wave from one transmission system or medium and transmits a wave containing equivalent information to a different system or medium.

Transistor

A three-terminal electrical device made of semiconductor material and capable of performing amplification or switching of electrical signals.

Transmission levels

The signal levels (input and output), expressed in dBmV, that system amplifiers are operating at, or are designed to operate at, in a CATV system.

Transmission loss

The ratio, expressed in decibels, between the level of power at the input to a system, cable, or device, and the level of power at the output.

Transmitter

In a fiber optic system, the device which converts a modulated electrical signal into an optical signal for transmission through a fiber. A transmitter typically consists of a light source (LED or diode laser) and driving electronics.

Triple beat distortion

Spurious signals generated when three or more carriers are passed through a nonlinear circuit. The spurious signals are sum and difference products of any three carriers, sometimes referred to as "beats." Triple beat distortion is calculated as a voltage addition.

Trunk

1. One telephone communication channel between (a) two ranks of switching equipment in the same central office, (b) between central office units in the same switching center, or (c) between two switching centers. A trunk is for the common use of all calls of one class between its two terminals.

2. A sub-system within a trunk plus feeder designed CATV system which provides somewhat limited, arterial distribution of signals broadly across the CATV service area.

Trunk plus feeder design (trunk/feeder)

A technique for designing CATV systems which involves two or more transmission levels, applied within different sub-systems of the same system. Generally requires some significant amount of paralleling cable placement.

TVRO

An abbreviation for "television receive only." Defines a facility which can include antennas, preamplifiers, and receivers for the reception only of television signals from a geostationary satellite in space.

Two-way

Describing a transmission system which can transport signals in both directions simultaneously.

Two-way filter

A combination of low and high pass filters to subdivide spectrum in a CATV system, allocating some spectrum for transmission in one direction, and some spectrum for transmission in the opposite direction.

T-1 carrier system

A 24-channel, transistorized, time-division, pulse-code modulation, voice carrier used on exchange cable to provide short-haul trunks. Uses two pairs, in one or two cables, for two directions of transmission. Requires regenerative pulse repeaters at 6000 feet intervals.

- U -

Ultra-high frequency (UHF)

The radio spectrum between 300 and 3,000 MHz. The term UHF is also commonly used to denote standard television channels 14 through 69, which fall within this spectrum.

Ultraviolet

Electromagnetic radiation with wavelengths between about 40 and 400 nanometers. Radiation between 40 and 200 nm is termed "vacuum ultraviolet" because it is absorbed by air and travels only through a vacuum. The "near" ultraviolet has wavelengths close to those of visible light; the "far" ultraviolet has shorter wavelengths.

Underground cable

Cable installed in subsurface conduits terminating at intervals in manholes, thus permitting the placing, replacing, or removal of cables at will.

Usable gain

See Gain, usable.

- V -

Velocity of light

The velocity of light in a vacuum is 2,997,925. meters per second or 186,280 miles per second. For rough calculations the figure of 3,000,000 meters per second is generally used.

Very high frequency (VHF)

The radio spectrum between 30 and 300 MHz. The term VHF is also commonly used to denote standard television channels 2 through 13, which fall within this spectrum.

Vestigial side band (VSB)

In amplitude-modulated transmissions, a portion of only one sideband of a modulated carrier. The modulated carrier is passed through a filter having a graduated cut-off characteristic near the carrier frequency. A substantial portion of the modulated carrier is suppressed in this fashion.

Video

1. Pertaining to the signal which carries a television picture.
2. Describing the four megahertz wide band of frequencies which constitutes a television signal.

Visible light

That part of the spectrum to which the human eye is sensitive, usually defined as wavelengths between 390 and 780 nanometers.

Voice channel

A transmission path suitable for carrying analog voice signals, covering a frequency band of 250-3400 Hz.

- W -

Watt

The unit of electric power, equal to the rate of work when a current of one ampere flows under a pressure of one volt. For direct currents, it is equal to the product of the voltage and current, or the product of circuit resistance by the square of the current. For alternating currents it is equal to the product of effective volts and effective current times the circuit power factor.

Wave

1. A periodic variation of an electric voltage or current.
2. A wave motion in any medium: mechanical as in water, acoustical as sound in air, electrical as current waves on wires, or electromagnetic as radio and light waves through space.

Waveguide

Any device which guides electromagnetic waves along a path defined by the physical construction of the device.

Wavelength

The distance between three consecutive nodes of a wave, equal to 360 electrical degrees. It is equal to the velocity of propagation divided by the frequency, when both are in the same units.

Wavelength division multiplexing (WDM)

The provision of two or more channels over a common optical waveguide, the channels being differentiated by optical wavelength.

Wideband

Passing a wide range of frequencies.

Review Questions

These questions are intended for the use of group instructors using the book as a technical text in a seminar or course of study, or for the private review by individual students or readers. This is a series of general questions designed to evaluate or reinforce the readers comprehension and are presented for each Chapter of the book. These questions will enhance any course of study, be it formally as a group or privately as individuals.

Chapter 1

1. All "wideband" systems, including Cable Television systems, use digital modulation and signal multiplexing exclusively. True or False? ______
2. Conventional Cable Television systems may employ signal frequencies up to, and possibly including, commercial UHF broadcast frequencies. True of False? ______
3. The electromagnetic spectrum generally referred to as "microwave frequencies" falls between the Radio and TV spectrum and lightwave frequencies.True or False? ______
4. Radio, sound, and light waves are all Alternating (AC) waves. True or False? ______
5. At higher frequencies, wavelengths are shorter. True or False? ______
6. A coaxial cable transmission system presents significant transmission bandwidth for private allocation and use. Federal licensing is required for each and every Television frequency carried. True or False? ______
7. A standard commercial broadcasting Television signal occupies the following spectrum:
    a)3 mHz
    b)5 mHz
    c)6 mHz
    d)8 mHz ______
8. The video carrier of a standard commercial broadcasting Television signal employs the following modulation:
    a)Frequency Modulation
    b)Digital Modulation
    c)Phase Modulation
    d)Amplitude Modulation ______
9. In any standard commercial broadcasting Television signal, both signal side bands are fully transmitted on air. True or False ______
10. The direction of transmission from the subscriber stations on a conventional Cable Television system back to the system point of origination, or Head End, is generally called the "downstream" transmission. True or False? ______
11. A Mid-Split coaxial cable system generally carries standard Television signals on Channel 2 through Channel 6 on standard broadcasting frequencies from the Head End to all subscribers. True or False? ______
12. Using coaxial cable technology, only one direction of transmission is possible on any single coaxial cable. True or False? ______
13. Due to the transmission losses incurred at Cable Television frequencies on coaxial cable systems, relatively frequent reamplification of signals is required. True or False?______

14. Different sizes of coaxial cable introduce different transmission loss at any given frequency. True or False? ______

15. Unity gain is a term employed to describe the signal level of any single Television signal as it passes through a coaxial cable transmission system. True or False? ______

Chapter 2

1. The two basic factors in a coaxial cable system, as in any transmission system, are loss and gain. True or False? ______

2. In any coaxial cable system such as a Cable Television system, we make cumulative calculations of signal as presented to each and every point of service within that system. True or False? _____

3. The decibel can be used to denote any particular signal level at any point in a system. True or False? ______

4. The transmission gain of any particular amplifier in any system can be accurately stated in dBmV. True or False? ______

5. A ratio can be used to denote any specific level or quantity of signal in a transmission system. True or False? ______

6. The decibel is one fifth of a Bel. True or False? ______

7. A Bel, or a decibel, may be either negative or positive in value.True or False? ______

8. There is a definite relationship between power ratios and decibels.True or False?______

9. Bels and decibels are not logarithmic. True or False? ______

10. Every number, positive or negative, has a logarithm. True or False? ______

11. The log of a number is the exponent to the base ten that produces that number. True or False? ______

12. The formula to determine the ratio in decibels between two power levels is: ______

a) $dB = 20 \log \dfrac{P_2}{P_1}$

b) $dB = \log \dfrac{P_2}{P_1}$

c) $dB = 10 \log \dfrac{P_2}{P_1}$

13. Given an input to a device of 300 watts and an output of 3,000 watts, what is the power ratio in dB? ______

a) - 10 dB
b) + 10 dB
c) + 20 dB
d) + 30 dB

14. One half the power is a power ratio of 3 dB. True or False? ______

15. Zero decibel-millivolts (0 dBmV) is equal to: ______
    a) .001 Volts across 50 Ohms
    b) 10^{-3} Volts across 75 Ohms
    c) 10 millivolts across 75 Ohms
    d) A power ratio of 10 dB

16. The reference power level of 0 dBm is equal to +48.76 dBmV. True or False? ______
17. A power ratio in dB can be directly added to, or subtracted from, a power level in dBmV, and the result will be a power level in dBmV. True or False? ______
18. Ohm's Law states that

$$I = \frac{E}{R}, \qquad E = I^2 \text{ x } R, \qquad R = \frac{E}{I}$$

True or False? ______

19. The terms decibel, watt, horsepower, and decibel-millivolt are all terms that denote levels of power. True or False? ______
20. In any given example, if measurements are given as either Power or Voltage, and the correct formulas are applied to the calculations, the proven results will be the same. True or False? ______

Chapter 3

1. The term generally used to denote number of amplifiers serially connected is: ______
   a) Tandem
   b) Parallel
   c) Cascaded
   d) Tiered
2. All amplifiers require operating power. True or False? ______
3. In most Cable Television amplifiers in bi-directional use today, each such amplifier provides ______ separate and distinct transmission paths through it.
   a) Two
   b) One
   c) Four
   d) Three
4. The system power carried on the coaxial cables to power the intermediate amplifiers is 60 Hertz AC. True or False? ______
5. A splitter in a coaxial transmission system divides its input across any number of outputs on a power ratio as given by the splitter's given value in dB. True or False? ______
6. Directional couplers, as used in outside coaxial cable systems only pass operating power to the through connection of the coupler, not to the tap connection as well.
   True or False? ______
7. If a subscriber tap were spliced into a coaxial cable system backwards, that is, with its Line In and Line Out cable ports reversed, there would be no significant difference in the signal levels at any subsequent point along the coaxial cable system itself.
   True or False? ______

8. Subscriber taps have different transmission loss to the drop cables they feed according to their tap value as given in dB, but all subscriber taps have the same insertion loss into the coaxial cable system itself. True or False? ______
9. A graphic map symbol of a square, with a one or two digit numeral within that symbol, denotes a tap with how many service drop output ports? ______
   - a) Four
   - b) Two
   - c) One
   - d) Eight
10. Active subscriber taps are somewhat sophisticated and do require and consume some operating power. True or False? ______
11. Directional couplers and splitters as employed in system Head Ends or at subscriber premises do not usually pass power through them. True or False? ______
12. If a coaxial cable system must provide a transmission bandwidth of say 600 mHz, all system amplifiers must have equal or better bandwidth, but no requirement for bandwidth need be applied to the system directional couplers or splitters.True or False? ______
13. In most coaxial cable systems in service today, AC power is fed along the system coaxial cables and into all system service drops as well. True or False? ______
14. An attenuator or "pad" is used at the input to an amplifier to introduce frequency response distortion to overcome, or counteract, any frequency response distortion which may have been introduced by the cable section immediately preceding that amplifier. True or False? ______
15. The minor irregularities in frequency response of passive devices such as taps, is sometimes called the "signature" of such units. True or False? ______
16. Subscriber taps are supplied in a variety of values, given in decibels (dB). These several values are only required and applied in systems that carry twenty television signals or more. True or False? ______

Chapter 4

1. In coaxial Cable Television systems, we generally address the Signal-to-Noise Ratio (S/N) in all system deliberations or calculations. True or False? ______
2. The noise in an analog broadband system is stated to be that noise power ratio present in any 4 mHz portion of system spectrum that is occupied by a single television signal. True or False? ______
3. The thermal noise level is a function of molecular movement within any device, and reflects the bandwidth of that device as well. Across 75 Ohms the noise power present in 4 mHz can be calculated to be -59 dBmV. True or False? ______
4. Individual units of equipment such as amplifiers, receivers, etc. are specified by their manufacturer as to their noise contribution above this irreducible level by the term "threshold," specified as a single figure in dBmV. True or False? ______
5. Since in a coaxial cable system, we are concerned with the cumulative noise in the system, and since the system carries only modulated carriers between its own interfaces, we use the term Carrier-to-Noise Ratio (C/N) for all system deliberations, specifications, and calculations. True or False? ______

6. An equalizer at the input to an amplifier attempts to correct all signals to the same level for input to that amplifier. This is done so that all signals presented to that amplifier will enjoy the same C/N Ratio. True or False? ______

7. If in an operating coaxial cable system we raise the input signal to an amplifier by 3 dB, the C/N Ratio of that amplifier will: ______
   a) Increase by 6 dB
   b) Decrease by 6 dB
   c) Increase by 3 dB
   d) Decrease by 3 dB

8. If in an operating coaxial cable system with two amplifiers in cascade we raise the input signal to both amplifiers by 3 dB, the C/N Ratio of the cascade of two units will:
   a) Increase by 6 dB
   b) Decrease by 6 db
   c) Increase by 3 dB
   d) Decrease by 3 dB

9. In a coaxial cable system used in Cable Television service to carry several or many television carriers, the number of channels carried has no relationship or effect on the C/N Ratio of any single channel as that channel is passed through any single amplifier.
   True or False? ______

10. The only information that a manufacturer has to give to evaluate the noise performance of an amplifier, and the noise performance of a cascade of such amplifiers, is the Noise Figure of that unit in dB. True or False? ______

11. If we double the number of identical amplifiers, and all amplifiers are operating at the same input signal level, the cascade C/N Ratio will: ______
   a) Increase by 6 dB
   b) Decrease by 6 dB
   c) Increase by 3 dB
   d) Decrease by 3 dB

12. We can take any two devices or two portions of a system which had different cascades of units, and calculate the C/N Ratio for each independently, but when we combine the two resultant C/N Ratios, we must degrade the worst C/N Ratio by: ______
   a) 6 dB
   b) 2 x the longest cascade C/N
   c) Combined C/N must be calculated
   d) Simply add the two C/N Ratio numbers

13. The formula for calculating the C/N Ratio of a single amplifier is: ______
   a) $C/N = NF + 10 \log Sig_{In}$
   b) $C/N = Sig_{In} - NF$
   c) $C/N = Sig_{In} + 59 - NF$
   d) $C/N = NF \times 10 \log Sig_{In}$

14. The formula for calculating the C/N Ratio of a cascade of amplifiers is: ______
   a) $C/N = C/N_{amp} + 10 \log N$
   b) $C/N = C/N_{amp} - 10 \log N$
   c) $C/N = N \times 10 \log C/N_{amp}$
   d) $C/N = C/N_{amp} \times N$ 15. The NF of an amplifier is always specified to be at the coaxial cable entrance port to the amplifier housing. True or False? ______

16. The C/N Ratio for any coaxial cable system as employed for Cable Television service is always given to be, and taken to be, the worst case within that system, that is, at the most distant subscriber location where all signals have passed through the maximum number of amplifiers. True or False? ______
17. The noise contributed by any amplifier is assumed to be constant, that is, at the same power level across the entire pass band of that amplifier. True or False? ______
18. At a C/N Ratio of 0 dB, the noise is at the same power level as the desired signal. True or False? ______
19. The system specifications always gives the specified C/N Ratio in dBmV. True or False? ______
20. A higher level of noise if the signal level remains constant is always a higher C/N figure. True or False? ______

Chapter 5

1. Intermodulation distortion takes several forms including cross modulation, second order beats, triple beats, composite triple beats, etc. True or False? ______
2. Intermodulation distortion is not due to the linearity of an amplifier or to the composite RF energy it is required to pass through its output stage. True or False? ______
3. The number of television signals passed through an amplifiers is a factor in the distortion that unit will evidence. True or False? ________
4. Since intermodulation distortion is the result of several signals interacting with each other, we are not addressing the addition of power as we were with noise, but the addition of voltages. True or False? ______
5. If all intermodulation distortion is affected by the composite RF output of the unit, if we change the output level up or down, we would expect some drastic change in the distortion contribution of the unit. True or False? ______
6. To calculate the Cross Modulation (XM) distortion produced by a single amplifier when:

______

XM_{amp} = Cross Mod per amplifier
XM_{spec} = Cross Mod specified by the manufacturer
OL_{oper} = Output level operated at
OL_{spec} = Output level specified by manufacturer
then

a) $XM_{amp} = XM_{spec} + 2\,(OL_{oper} - OL_{spec})$
b) $XM_{amp} = 10 \log OL_{oper} - OL_{spec}$
c) $XM_{amp} = 2\,(OL_{spec} - OL_{oper}) + 10 \log XM_{spec}$
d) $XM_{amp} = \log XM_{spec} + 2(OL_{oper} - OL_{spec})$

7. The Output Level specified by a manufacturer for an amplifier is the recommended operating output level of that unit in service. True or False? ______
8. For all noise considerations or calculations, all the manufacturer needed to give us was one number, Noise Figure. The intermod distortion requires a more sophisticated and comprehensive description from the manufacturer if the information is to be adequate or useful. True or False? ______

9. To calculate the Cross Modulation (XM) performance of a cascade of similar amplifiers, all operating at the same output level and all carrying the same number of channels, when:

______

XM_{sys} = Cross Mod for the system
XM_{amp} = Cross Mod for an amplifier
N = Number of units in cascade
then

a) $XM_{sys} = XM_{amp} + 10 \log N$
b) $XM_{sys} = XM_{amp} + (10 \times N)$
c) $XM_{sys} = \log N + XM_{amp}$
d) $XM_{sys} = XM_{amp} + 20 \log N$

10. If we raise the Output Level of an amplifier by 2 dB, the Cross Mod will: ______

a) Decrease by 4 dB
b) Increase by 2 dB
c) Increase by 4 dB
d) Decrease by 2 dB

11. To combine two Cross Mod figures, perhaps from different sections of a system, we need only add the two figures together and then subtract 2 dB from the result.
True or False? ______

12. If we "tilt" all the signals passed through an amplifier inter-stage, that is, before we pass through the final, output stage of an amplifier, we will: ______

a) Have no effect on amplifier intermod
b) Improve the Noise Figure of the unit
c) Degrade the amplifier C/N Ratio
d) Improve the amplifier intermod distortion

13. In order to adequately specify the intermod distortion of an amplifier, the manufacturer must specify the Noise Figure, number of channels carried when distortion was measured, amount of distortion measured, and the output level at which the amplifier was operated while the measurement was made. True or False? ______

14. An equalizer at the input of an amplifier is installed primarily to improve the intermod distortion of the amplifier at all output levels. True or False? ______

15. If we decrease the output level of all identical units in a cascade of amplifiers by 1 dB, we would expect the system Composite Triple Beat distortion to: ______

a) Remain the same
b) Increase by 2 dB
c) Decrease by 2 dB
d) Decrease by 1 dB

16. We can combine different intermod figures by using graphs to produce a composite system or network intermod figure. True or False? ______

17. Since all forms of intermod distortion are equally affected by the composite RF energy passed through the output stage of an amplifier, any reduction in operating output level will have an equally beneficial effect on all forms of intermodulation distortion.
True or False? ______

18. Intermod distortion figures are negative and given in dB. The best intermod performance is indicated by: ______
    a) - 48 dB
    b) - 58 dB
    c) - 41 dB
    d) - 36 dB
19. If we increase the operating output level of an amplifier 2 dB from the manufacturers stated output level when he measured the intermod distortion he reported, we would expect that unit to introduce less distortion than the manufacturer reported.
    True or False? ______
20. To qualify the distortion that any manufacturer reports for an amplifier, he must include information as to the operating conditions under which he made such distortion measurements. True or False? ______

Chapter 6

1. Given a cascade of identical amplifiers, if the gain of all units remains the same and we raise the input signal levels by 1 dB at the cascade input, the system C/N Ratio will improve and increase by 2 dB. True or False? ______
2. If the gain of all identical amplifiers in a cascade remains the same, we can change the end of system performance either in actual practice or during trial designs of the system, by raising or lowering the system input signal levels. True or False? ______
3. In a cascade of identical amplifiers, we can change input levels and if the gain remains unchanged, output levels would change as well, of course. This can change the C/N Ratio and the intermod distortion of the cascade, and thus we can change the economic cost of the system. True or False? ______
4. We must know the channel loading of an amplifier which produced the manufacturer-specified intermod performance if we are to develop amplifier intermod and system intermod for any given operating output levels. True or False? ______
5. If all amplifiers in a cascade provide the same gain, and thus permit the same spacing in the system, we only change the end of system performance by changing operating signal levels, not the spacing, and thus not the economics of the cascade either.
   True or False? ______
6. The gain of an amplifier establishes the relationship of input signals and output signals in a cascade of amplifiers, and thus establishes the end of system C/N and intermod performance that is possible in that system. True or False? ______
7. In any system of any length, the economics of the system cannot be changed by changing the gain of the amplifiers employed. True or False? ______
8. Any system may include sections that utilize a different amplifier, with different gain, and producing different C/N and intermod performance. True or False? ______
9. If different sections of a system do employ different amplifiers with different performance, the end-of-system performance is taken to be the same as that of the poorest performing section of the system. True or False? ______

10. In a trunk/feeder system the trunk plant is best characterized by: ______
    a) Low noise and high intermod
    b) High noise and low intermod
    c) Inexpensive and cost effective
    d) Requires no AGC
11. In effect, the feeder in a trunk/feeder system is really a second sub-system using different amplifiers and different operating signal levels. True or False? ______
12. The development of trunk/feeder systems was primarily dictated by economics. True or False? ______
13. The feeder plant in a trunk/feeder system may best be characterized by: ______
    a) High noise and low intermod
    b) Must include AGC
    c) Low noise and high intermod
    d) Long cascades of amplifiers
14. Where the area to be served is large but there are few if any large clusters of subscribers to be served, a trunk/feeder design will always be the most economical. True or False? ______
15. We can realistically extend one type of plant, call it trunk, through to a second type of plant, call it feeder, and determine the C/N and intermod performance of each section by itself, and then combine these performances into an overall system transmission performance. True or False? _____
16. We cannot design a system that utilizes only one type of amplifier throughout and one cable to distribute all signals throughout the area, as well as serving to feed all subscribers drops in the area. True or False? _____
17. The plant configuration generally called "Super-trunk" may best be characterized by: ______
    a) Smaller size cables
    b) Low noise low distortion
    c) Serves many subscriber drops
    d) High noise high distortion
18. If we can realistically extend one type of cable plant on through to a second type of plant and determine the C/N and intermod performance of each section by itself, and then combine these performances into an overall system transmission performance, then we can do this when we incorporate any other type of transmission system also, microwave for example, or lightwaves on optical fibers. True or False? _____
19. When we use the term "usable amplifier spacing" we aredenoting the actual physical spacing of the units as determined solely by the coaxial cable losses involved. True or False? ______
20. A coaxial cable system can be, and sometimes is, operated as broadband analog systems. An optical fiber utilizing lightwaves can, and sometimes is, operated as broadband analog systems. A microwave system cannot, and is not, sometimes operated as broadband analog systems. True or False? ______

REVIEW QUESTIONS

Chapter 7

1. We define the quality of transmission through a coaxial cable system as the minimum or total absence of visible impairment in the television pictures that are transported by the system. True or False? ______
2. Changes in the ambient temperature of the cable and equipment used in a cable system causes changes in the transmission performance of all cable systems. True or False?

   ______
3. There are no other factors that introduce noise into the television signals that are carried other than the contributions of the cable plant itself. True or False? ______
4. Specifications for the performance of the cable plant itself are necessary, but one factor that is not involved is:
   a) To establish cable plant objectives ______
   b) To prove in performance after construction
   c) To accommodate HBO and other special services
   d) To set standards for long term maintenance
5. In any cable system, as the plant extends through more amplifiers, the system C/N Ratio will get worse. True or False? _____
6. In an operating system, a lower figure for system C/N Ratio would be better performance than a higher figure. True or False? ______
7. A lower figure, that is, a more negative figure, is better Composite Triple Beat (CTB) in a system. True or False? ______
8. The system C/N Ratio will increase or decrease 1 dB for every 1 dB change in amplifier input level. True or False?______
9. The system Triple Beat will improve or degrade 1 dB for every 1 dB change in amplifier output level. True or False? ______
10. Combining two equal C/N Ratios will degrade the result by 3 dB from either of the two alone. True or False? ______
11. Combining two equal Cross Modulation figures will degrade the result by 3 dB from either of the two alone. True or False? ______
12. If a system were to be operated at relatively high signal input levels, as the feeder plant in a trunk/feeder system for example, the selection of feeder amplifier Noise Figure would be very important. True or False? ______
13. In any Cable Television system, the one factor that the system designer does not have any control of is: ______
    a) The noise present in any satellite signals
    b) The intermod contributed by the cable plant
    c) The level of signal at all receivers served
    d) The quality of the subscriber-owned TV set
14. In a cascade of amplifiers, the intermod will not increase gradually, to the point where it is not within system specifications and is no longer usable. True or False? ______
15. The system specifications establish a signal level to be presented to each subscriber's television set within a small range of acceptable signal levels. True or False? ______
16. Noise or intermod distortion in a system will, at some level, become visible to the subscribers. True or False? _____

Chapter 8

1. A coaxial cable really has only one significant conductor. True or False? ______
2. On any conductor carrying Alternating Currents, the higher frequencies tend to flow nearer the outer portion of any conductor than the lower frequencies do. This is called the "skin effect." True or False? ______
3. If higher frequency currents tend to flow in only some portions of a conductor, near the outer portions primarily, this has the same result as reducing the conductor dimension for the higher frequencies. True or False? ______
4. The practical effect of the "skin effect" on coaxial cables carrying relatively high RF carriers, as a Cable Television system does, is that we experience less transmission loss at Channel 2 (54 mHz) than we do at Channel 13 (216 mHz) for example. True or False? ______
5. All transmission lines have a characteristic impedance and we may, in the design and manufacture of coaxial cable, determine and assure that this characteristic impedance is what we wish it to be. True or False? ______
6. The characteristic impedance of coaxial cable is always a function of the outer diameter of the outer cable conductor alone. True or False? ______
7. At the frequencies we are most concerned with in Cable Television transmission, a 75 Ohm characteristic impedance produces the minimum transmission loss from any other impedance. True or False? ______
8. The characteristic impedance of RG-59, a coaxial cable frequently used in service drops or cabling within a subscribers premises, is 50 Ohms. True or False ______
9. A .750" diameter coaxial cable has a lower characteristic impedance, and thus a lower transmission loss, than a .500" diameter cable. True or False? ______
10. A coaxial cable with an air dielectric separating the two metallic conductors, will have less transmission loss than that same size cable using a foamed (air entraining) dielectric. True or False? ______
11. If we maintain the ratio in diameter of both the outer and inner conductors, we can manufacture coaxial cable with any given characteristic impedance regardless of its outer dimension. True or False? ______
12. All coaxial cables operating at Cable Television frequencies exhibit a difference in loss at different frequencies. True or False? ______
13. The transfer of energy between two cables, a cable and a device, or two devices is most efficient when both items have the same characteristic impedance. True or False? ______
14. The return loss of a device, a subscriber tap for example, means: ______
    a) Transmission loss upstream through the device
    b) The tap may have been inserted backwards
    c) Some input energy will reflect back into the cable
    d) Through tap loss is different coming or going
15. When reflected energy is confined to only part of the spectrum occupied by a television signal, it is called a reflection. True or False? ______

16. The visible effect of a reflection in a television picture does not depend on: ______
    a) The amplitude of the reflection
    b) What frequency or channel is tuned in
    c) The time delay between the reflected signal and the original signal
    d) The nature of the video information itself may make it more, or more quickly, objectionable.
17. When impedance mismatches are present, some energy is reflected back. If those mismatches occur because of manufacturing processes of the coaxial cable itself, this loss is referred to as "structural return loss." True or False? ______

Chapter 9

1. When coaxial cable is colder, it has greater transmission loss.True or False? ______
2. If we are to maintain signal levels to all subscriber stations within a specified range across a wide range of ambient temperature, we must provide some level of Automatic Regulation in all coaxial cable systems. True or False? ______
3. If signal levels to subscriber are allowed to vary as ambient temperature changes and thus cable losses change, some or all system subscribers would go out of signal level specifications and may find the service unsatisfactory and terminate. True or False? ______
4. We cannot sense system signal levels on a carrier that is modulated with video information. True or False? ______
5. If we do sense system signal levels, we cannot control amplifier output signals by switching in or out, attenuation as the sensing circuitry dictates. True or False? ______
6. We must use, and add to each system, separate Pilot Carriers for all system regulation sensing. True or False? ______
7. Automatic Gain Control (AGC) usually senses a single carrier level and removes or introduces "flat" loss, that is, loss that is the same across the entire passband of the amplifier. True or False? ______
8. Automatic Slope Control (ASC) is provided in broader band systems to permit some level adjustment for different portions of the system spectrum, because the transmission losses incurred across different portions of the system spectrum may be excessive and unacceptable. True or False? ______
9. If, in Automatic Slope Control (ASC) amplifiers, we wish to make corrections or adjustments on different portions of the system spectrum, then we must sense signal levels on more than one carrier and at different points in that spectrum, to provide for more than one correction. True or False? ______
10. The normal ambient temperature for cable plant, for purposes of system self-regulation, is taken to be +48 degrees Fahrenheit. True or False? ______
11. At 90 degrees Fahrenheit, if an AGC amplifier is set to have +3 dB and -3 dB input level correction capability to maintain an output level of +1 or -1 dB, its manual gain control should be set to deliver the specified amplifier output level. True or False? ______
12. If an AGC amplifier is not adjusted correctly, it may have the capability of +1 dB and -5 dB input signal level correction, even though it was intended to provide a +3 dB and -3 dB input level correction, and was designed and is capable of a +3 and -3 correction range. True or False? ______

13. Even if all AGC amplifiers in a system were not adjusted correctly, the end-of-system performance would not go out of specifications if the area ambient temperature was -10 degrees Fahrenheit. True or False? ______
14. Even if significant numbers of AGC or ASC amplifiers were improperly adjusted, at normal ambient temperature variations for that area, a system would not experience _______ .
    a) Periodic operating power failures
    b) Unusual numbers of subscriber complaints
    c) Periodic out of specification system transmission
    d) Unusual numbers of "No Trouble Found" reports
15. If a system suffers a total loss of the carrier or carriers it is regulating on, the end-of-system RF transmission continuity would be interrupted. True or False? ______
16. If a system suffers a total loss of the carrier or carriers it is regulating on, the end of system transmission quality would probably be out of specification. True or False? _____
17. When a technician is adjusting the AGC or ASC of any system amplifier, that adjustment can have an effect, good or bad, on the actual quality of the pictures that the system sells to the subscribers. True or False? ______
18. If the AGC or ASC of a system is improperly adjusted, that system may go out of transmission specifications at some temperatures, even though the system engineer and designer put in enough self-regulation at the proper intervals, the amplifiers themselves were initially selected to be adequate, and all equipment is operational and functional to its own specifications. True or False? ______

Chapter 10

1. If a system places regulating amplifiers at every third station, on a very hot day, when cable losses are higher than usual, we expect that 2 out of 3 amplifiers would receive low input signals and thus would have better than usual C/N Ratio performance. These would be the two units located between any two Automatic Regulation amplifiers. True or False? ______
2. Intermod contributions would not be affected by temperature changes and thus would not be better or worse as temperatures go up or down. True or False? ______
3. If noise contributions in a system increased due to hotter ambient temperatures, then intermod contributions would decrease. True or False? ______
4. An engineer decides how much, and how often, Automatic Regulation should be located within a system based upon the ambient temperatures to be expected and on the distances between amplifier locations. True or False? ______
5. Automatic Slope Control (ASC) is generally installed in systems that have greater bandwidth and that pass higher frequencies. True or False? ______
6. In underground plant, more Automatic Regulation is generally required. True or False? ______
7. As a general rule, higher gain amplifiers in a system require more Automatic Regulation than lower gain amplifiers. True or False? ______

8. If Automatic Regulation amplifiers are placed at every station within a system, then individual units require, and should provide, less regulating capability, that is, they might be equipped to maintain an output at plus or minus 1 dB with input changes on the order of 2 dB or even less and not +4 and -4 as older units provided. This condition might offset ______.
   a) A loss of regulating carrier, all Automatic units would switch out all remaining attenuation and thus raise output levels excessively.
   b) This could substantially reduce the complexity and cost of automatic regulating units.
   c) The operating power required of regulating units would be less.
   d) It doesn't matter what the correction range of regulating units is.
9. Since there is no relationship of customer complaints or service calls to sufficient and properly adjusted AGC in a system, the cost of Automatic Regulation will not result in lower system operating costs over an extended period of time. True or False? ______
10. In a trunk/feeder system, Line Extender amplifiers do not usually provide any Automatic Regulation at all. True or False? ______
11. In hybrid systems which might include optical fibers to feed limited sections of conventional coaxial plant with limited cascades of amplifiers involved, the provision of Automatic Regulation in that coaxial plant may not be mandatory if the cable lengths to be fed are nominal and the cascade of amplifiers is limited. True or False? ______
12. On loss of a regulating carrier, most AGC units "fail hard," that is, they do not restore or maintain neutral attenuation insertion, they open up and remove all attenuation. This can produce unacceptably high output signal levels into all regulating units and into the system in general, which may put the end of system performance out of specifications. True or False? ______
13. When Automatic units fail in regulatory action or are improperly adjusted, a complete interruption of RF continuity in the system will occur and no subscriber service at all is possible beyond that point in the system. True or False? ______
14. On loss of regulating carrier, most AGC units automatically readjust to the mid-range of the units RF attenuation, and hold that until the regulating carrier is restored, when normal AGC action resumes. True or False? ______
15. Most modern systems today, particularly those with extended transmission bandwidth, use two regulating carriers and provide Automatic Slope Control (ASC) as well as Automatic Gain Control (AGC). True or False? ______
16. The single most common and most service-affecting incorrect adjustment in Cable Systems today is in AGC and/or ASC adjustment. True or False? ______

Chapter 11

1. We generally ignore the minor frequency response distortion sometimes referred to as "response ripple" that is introduced by the amplifiers and passive devices in a cable system. True or False? ______

2. What is more extreme in nature, and must be corrected in a system if possible, is the "tilt" in signal levels due to the cable itself having greater loss at higher frequencies.
True or False? ______
3. Equalization is a technique to reestablish a relationship between transported signals that were introduced by the different transmission losses of the coaxial cable that the signals have passed through. True or False? ______
4. Each amplifier is not intended to offset, as nearly as possible, the loss of the cable section immediately preceding it and the amplifier equalizer is intended to offset, as nearly as possible, the signal "tilt" that has been introduced by the preceding section of cable. True or False? ______
5. Since we are concerned that all signals are equally protected against noise, we want all signals to be presented to the amplifier gain module, where the Noise Figure has been specified, at, or nearly at, the same level. True or False? ______
6. The equalizer then, is directly associated with the amplifier gain module itself, and does not reflect the length of cable, or the signal "tilt" it may introduce, which immediately precedes the amplifier. True or False? ______
7. Equalizers do __________.
    a) Introduce different gain at different frequencies.
    b) Introduce the same loss at all frequencies passed
    c) Introduce different loss at different frequencies
    d) Introduce different gain at different frequencies
8. Even minor imperfections in cable, if periodically spaced and repeated many times, can have dramatic influence on a cable's frequency response. True or False? ______
9. When a cable introduces a sharp and deep loss characteristic affecting only a small section of its response, this effect is sometimes called a "suck-out." True or False? ______
10. We "tilt" the output of an amplifier to minimize the frequency response variations experienced along the next section of cable, sometimes to help equalize signal levels to subscriber drops fed along that section. True or False? ______
11. Cable equalizers are not always associated with, or enclosed within, amplifiers alone.
True or False? ______
12. The service drop cables themselves also introduce differences in frequency response due to their different loss at different frequencies. True or False? ______
13. If an amplifier fails completely, or evidences an unusual frequency response, its replacement requires the replacement of the cable equalizer also. True or False? _____
14. By"tilting" the signals inter-stage in an amplifier, that is, before we enter the last stage of amplifier gain, we can also improve the amplifier Noise Figure. True or False? ______
15. In systems presenting greater bandwidth for transmission use, Automatic Slope Control (ASC) is almost always provided. True or False? ______
16. Although it is not practically attainable, the objective in all cable systems is to feed all served TV receivers with the same signal level on all channels carried.
Equalization helps us come closer to the objective. True or False? ______

REVIEW QUESTIONS

Chapter 12

1. The questions of amplifier gain, input and output levels, Automatic Regulation, and system performance specifications are all a function of system engineering, not system design or layout. True or False? ______
2. System layout or design is obliged to meet all system specifications as established by others, such as tap outputs to each drop, amplifier input and output levels, AGC and ASC locations, etc. True or False? _____
3. System layout or design does not select tap and coupler values to meet its required specifications. True or False? ______
4. The selection of a tap value during the design phase of any system requires that the tap Noise Figure be known and considered. True or False? ______
5. Although the use of in-line equalizers may be dictated by system engineering, the location and value of such units is a function of the system layout process.
   True or False? ______
6. The inclusion of attenuator pads and their values at amplifier inputs is dictated by the engineering specification for amplifier output levels. True or False? ______
7. In establishing a design specification for tap levels to each service drop, the size and loss of service drop cables to be used need not be considered. True or False? ______
8. The design process need not address the number of inserted taps or their value in establishing the next required amplifier location. True or False? ______
9. Cumulative transmission loss and signal level calculations are required as a system design is being done. True or False? ______
10. Subscriber taps cannot be spliced into a cable system backwards.True or False?______
11. If at some later date after a system is in operation, a new subscriber station is installed and is the first drop connected to a tap, and the signal level at the subscribers premises is unusually low, the trouble may be ______.
    - a) The last amplifier gain is set too low
    - b) The tap itself probably needs replacement
    - c) The operating power in that section is out
    - d) The tap may have been spliced in backwards
12. Many systems are designed with the aid of computer programs that automatically make all necessary calculations. True or False? _____
13. If, in superficially examining a system design, we notice a large number of high value amplifier input pads are frequently included, we might suspect ______.
    - a) The system offers usable bandwidth to 800 mHz
    - b) The system carrys many satellite channels
    - c) The system design was not very efficient
    - d) All taps should have been 26 dB units
14. Back-feed cable can be used in systems to serve awkwardly located subscribers premises. True or False? ______
15. If signal levels in a system, or in any section of a system, can be kept at a higher level, the efficiency of subscriber tapping will be improved. True or False? ______
16. In trunk/feeder systems, the feeder plant is operated at the same signal levels as the trunk plant is. True or False? ______

17. All feeder amplifiers have significantly greater gain than trunk amplifiers.
True or False? ______

18. Bridger modules are included in trunk amplifiers to raise the signals into the feeder plant to different levels than the signal levels in the trunk plant. True or False? ______

19. Trunk plant usually costs less than feeder plant in a trunk/feeder system.
True or False? ______

20. In a trunk/feeder system, there is usually more trunk plant than feeder plant.
True or False? ______

Chapter 13

1. A two way splitter always distributes its input equally across two outputs, and both outputs have the same transmission loss through the splitter. True or False? ______

2. A three-way splitter may have equal losses to all three outputs or it may have one higher level output and two equal, lower level outputs. True or False? ______

3. Directional couplers come in a variety of values given in dB. True or False? ______

4. A directional coupler provides some discretion to the system designer in allocating different signal levels to different output ports, and thus into different sections of a system.
True or False? ______

5. The transmission loss through any passive device as it is designed to be used in a system, be it a splitter or coupler, is the same in both directions of transmission.
True or False? ______

6. Tap values are selected for each location _____.
   a) To provide for 800 mHz operation
   b) Depending on the signal level available at that location
   c) To supply the specified signal level into the subscriber drop cable
   d) To feed operating power into the drop cable

7. Most systems present small sections that for geographic reasons could be designed more than one way and sometimes at different costs, both meeting all specifications.
True or False? ______

8. If, in examining a system design, we found a lot of cable ends that required attenuator pads of higher values, we might suspect that ______.
   a) The system was designed for 800 mHz operation
   b) The amplifiers in the system were operating at too high an output level
   c) The system, in general, was poorly equalized
   d) The system design was not as efficient as it might have been, nor as cost effective

9 If a system experienced a lot of subscriber complaints during short duration temperature extremes that resulted in no trouble found, we might suspect ______.
   a) The off-air signal levels are too low
   b) Some AGC or ASC amplifiers are inoperative or improperly adjusted
   c) System operating power is too low
   d) The system engineer specified the amplifierNoise Figure too low

10. Sometimes, in some systems, the geography of the service area dictate the inefficient use of an amplifier to feed only a few subscribers. This can always be overcome by good system design. True or False? ______

11. We cannot improve the economics of any system by simply changing the input and output signal levels alone. If the cable loss remains the same, we must change the amplifier gain to produce any change in the cost of the system. True or False? ______
12. If, by careful design, we do improve the trunk to feeder ratio in a trunk/feeder system, and still meet all specifications, we still could not improve the cost efficiency of the system. True or False? ______
13. If we reduce the cascade of RF amplifiers in a system, by incorporating lightwave transmission on optical fibers for example, then we might, since fewer RF amplifiers are cascaded, use higher gain units and higher operating signal levels as well. True or False? ______
14. The correct use of AGC and ASC units in adequate quantities in a system will produce significant economies in the long term operating costs of that system True or False? ______
15. Although improper spacing, operation, or adjustment of Automatic Regulating amplifiers may have an effect on picture quality delivered by a system, it does not automatically introduce system operating power outages. True or False? ______

Chapter 14

1. Urban systems may be defined as applications that require frequent tapping at frequent intervals for service, due to the density of housing in the service area. The service area itself may be local and limited to a smaller city or town. True or False? ______
2. Because of the multiplicity of taps generally all across the urban service area, the service taps themselves become a major consideration in the philosophy of design of such systems. True or False? ______
3. We have developed and refined system structures that do not necessarily reflect the nature of the service area, but are universally applied and predictably cost effective in any and all communities. True or False? ______
4. All Cable Television systems by the nature of the service they supply, can be considered to be Local in nature, that is, they generally serve only a single, somewhat limited area within or adjacent to a single community. There is no higher hierarchy of cable service serving a large area, as in the National Telephone network, for example. True or False? ______
5. Given the density of taps in an urban environment, there is still nothing we can do in the design of transmission systems to improve the efficiency of multiple tapping for service. True or False? ______
6. If we operate the cable plant, or even portions of it, at higher transmission levels, the efficiency of tapping for service does get better. True or False? ______
7. In urban cable systems, all system amplifiers operate at the same input and output levels. True or False? ______
8. There are no technical limitations on system operating levels. True or False? ______
9. Trunk/feeder systems operate both types of plant at the same transmission levels. True or False? ______
10. Feeder cable plant is installed primarily to provide a separate cable to install subscriber taps on. True or False? ______

11. Trunk plant is more cost effective than feeder plant because it uses larger cables and more Regulating amplifiers. True or False? ______
12. For purposes of calculating system noise and intermod, and because they are usually located within trunk amplifier housings, bridger amplifiers are considered part of the trunk system. True or False? _____
13. Trunk plant is not characterized by ______.
    a) Higher intermod contribution from each trunk amplifier
    b) Most system noise comes from the multiplicity of trunk amplifiers required
    c) Amplifiers have a better Noise Figure
    d) Usually use a larger size, lower loss cable
14. Feeder plant is actually a sub-system if you will, and operates at higher input and output levels. True or False? ______
15. Feeder plant may be characterized as ______.
    a) Lower operating input levels
    b) Most system noise is contributed by feeder
    c) Substantial system intermod comes from feeder
    d) Feeder amplifiers usually include AGC
16. When computing overall system transmission performance, the trunk and the feeder plant must be individually addressed as to their noise and intermod, and then both performance figures must be combined in some fashion. True or False? ______
17. Using smaller size cables and less sophisticated amplifiers, feeder plant is usually more cost effective than trunk plant. True or False? ______
18. Because the trunk cables must be paralleled by feeder cable in order to tap for service, trunk/feeder system require placing two cables throughout their entire length. True or False? ______
19. Due to their higher output levels, feeder amplifiers contribute more intermod. This is made tolerable in trunk/feeder systems by limiting feeder lengths and thus the cascade of high distortion producing feeder amplifiers. True or False? ______
20. If feeder costs less and there is more feeder than trunk in a system, then the cost of the higher grade trunk plant becomes acceptable. True or False? ______

Chapter 15

1. A rural service area may be defined as one requiring somewhat infrequent tapping for service due to the low population density, and further as that the tapping density is thinly distributed and random throughout the entire service area. The service area itself may be quite extensive however. True or False? ______
2. The rural areas lend themselves particularly well to conventional trunk/feeder system architecture. True or False? ______
3. In either urban or rural applications, the system engineer is still required to develop a transmission system that provides its subscribers with acceptable transmissionquality. True or False? ______

4. Since tapping is somewhat reduced and evenly distributed across a large area in a rural system, there is little advantage in trying to design one section of the system to operate at higher signal levels and thus to provide for efficient tapping, as a feeder system does in a trunk/feeder system. True or False? ______
5. In rural systems, only one or perhaps two types of amplifiers is employed. True or False? ______
6. Rural systems do not include ______.
   - a) One coaxial cable for both transmission and service tapping
   - b) Little Automatic regulation
   - c) Poorer C/N Ratios than urban designs
   - d) The same transmission levels throughout
7. Rural systems use the same basic design and operate at the same signal levels as urban trunk plant. True or False? ______
8. Rural systems use the same basic design and operate at the same signal levels as urban feeder plant. True or False? ______
9. Rural designs generally produce higher system cost per subscriber served. True or False? ______
10. In rural systems, amplifiers have _________.
    - a) More gain than urban trunk amplifiers
    - b) Less gain than urban trunk amplifiers
    - c) No AGC or ASC at all
    - d) Bandpass limited to 300 mHz
11. In rural systems, operating signal levels throughout the plant are __________.
    - a) The same as urban trunk plant
    - b) The same as urban feeder plant
    - c) Lower than urban feeder plant
    - d) Higher than urban feeder plant
12. Because of the extended service area in rural systems, most are limited in bandwidth to 300 mHz or so. True or False? ______
13. Rural systems operate ______ .
    - a) Higher than urban trunk plant levels
    - b) Lower than urban trunk plant levels
    - c) Higher than urban feeder plant levels
    - d) Lower than urban feeder plant levels
14. In a rural system, the computation of system noise and intermod distortion is simpler because each system amplifier operates at the same levels, and thus contributes equally to overall system noise and distortion. We need not combine two separate performance figures to compute overall performance. True or False? ______
15. The design approach to any system should reflect the area to be served and there are urban and rural designs, both technically sound, available to economically serve either environment. True or False? _____
16. In newer systems, where coaxial cable may be fed by lightwave transmissions on optical fibers and coaxial plant is limited in length, some adaptation of the rural, single cable design may well be the most practical solution. True or False? ______

Chapter 16

1. RF transmission on coaxial cable is just one form of transmission and it can be and is used in other ways than in simply serving Cable Television subscribers directly. True or False? ______
2. One older, and perhaps less common, application of coaxial cable is as Super-Trunk to distribute television signals some distance away or to several locations, for local distribution and use. True or False? ______
3. Since Super-Trunk anticipated that the signals would be applied to local coaxial cable plant, and thus would accumulate the local plant noise and distortion, the Super -Trunk plant was conservatively designed to introduce only nominal noise and distortion. True or False? ______
4. Super-Trunk used smaller sized cable for economy. True or False? ______
5. Super-Trunk always used higher gain amplifiers and higher operating signal levels than distribution plant. True or False? ______
6. Institutional cable is a relatively new addition in some cable systems, and involves the placement of separate coaxial cables in portions of the Cable Television system with the intent that these cables would provide data, telephone, or video services for industrial or commercial users only, and that the general public would not require access to these signals. True or False? ______
7. Institutional cables may not, and probably do not, incorporate Sub-Split design in two way systems, as is generally the case in conventional two way coaxial systems. They generally provide Mid-Split designs instead. True or False? ______
8. Systems designed and constructed as trunk/feeder plant cannot be extended in any other fashion, such as with single cable extensions, even if the noise or intermod at the point of plant extension would allow some contributions and still meet all system specifications. True or False? ______
9. Although the most common and perhaps best known applications of coaxial cable systems are in Cable Television service, coaxial plant can be and has been used in both LAN (Local Area Networks) and WAN (Wide Area Networks) for private audio, video, and/or data services. True or False? ______
10. If any of several different transmission techniques are combined in a single service, for example, optical fibers or microwave links feeding sections of coaxial cable, then the transmission performance of the overall system must combine the noise and intermod contributions from any and all such sub-systems. True or False? ______
11. If sub-systems are used to transport and deliver signals to coaxial plant, no processing of individual signals may be necessary, providing only that the transportation system is fully compatible with the distribution system feeds. An example might be optical fibers operated as broadband plant and feeding coaxial cables also operated as broadband plant. True or False? ______
12. In conventional Cable Television systems using RF distribution on coaxial cable plant, many individual signals are carried on a frequency division basis. True or False? ______

13. In a time-division multiplexed system, such as a conventional coaxial Cable Television system, we can tune in any of several signals carried on the system, either with a tunable meter or with a tunable television set. True or False?______
14. We specify transmission performance through the input and output interfaces of the coaxial cable system so we can engineer it, design it, construct it, and measure and demonstrate its performance alone. If we consider the actual signals that each subscriber receives, the cable system is really the only contributor of noise and distortion involved.
    True or False? ______

Chapter 17

1. Almost all cable plant constructed recently does have a bi-directional or two-way transmission capability. True or False? ______
2. Conventional cable plant is broadband in nature, using frequency division to separate all signals carried, in one direction of transmission. The opposite transmission direction is also broadband in nature. True or False? _____
3. Most conventional cable systems separate the two directions of transmission in a Sub-Split manner, that is, just below Channel 2. True or False? ______
4. In all two-way systems, there are filters at the input and output of all amplifiers to separate the two different directions of transmission as transmission spectrum dedicated to each direction. True or False? ______
5. Mid-Split two way systems normally provide _________ as the lower transmission spectrum provided. ______
    a) 50 mHz to 300 mHz
    b) 5 mHz to 108 mHz
    c) 5 mHz to 50 mHz
    d) 50 mHz to 600 mHz
6. In the return transmission path of a conventional two-way cable system, the noise contribution of all return amplifiers must be considered. True or False? ______
7. Separate calculations must be made for noise and intermod contributions for both directions of transmission, and the results must be calculated for the performance of transmissions from any system extremity to the system Head End and back out to that same extremity. True or False? ______
8. In considering intermod contributions on a loop back basis through a two way system, the intermod of all in-place return amplifiers must be considered, not just the units that are passed through. True or False? ______
9. In considering noise contributions on a loop back basis through a two-way system, the noise contribution of all in place return amplifiers must be considered, not just the units that are passed through. True or False? ______
10. Transmission from the Head End out to all subscriber stations is called _________ in two-way systems.
    a) Return Transmission
    b) Upstream Transmission
    c) Full Talk Transmission
    d) Downstream Transmission

11. At subscriber stations, the two directions of transmission and their spectrum must be separated by filters. True or False? ______
12. The amplifier locations in Downstream system design are dictated by the transmission levels as they are calculated. In the Upstream direction of transmission, the amplifier locations are also dictated by transmission levels. True or False? ______
13. We may find a large number of attenuator pads at the input of return amplifiers, and we should not expect this phenomenon to be wide spread. True or False? ______
14. A two-way system employed to allow subscribers to individually, one at a time that is, transmit toward the system Head End, may be called ______.
    a) Interactive Service
    b) Full Talk Transmission
    c) Interrogative Time-Shared Transmission
    d) Performance Monitoring
15. The two-way capability of RF broadband transmission systems may result in many new services on such plant, including perhaps data networks or plain old Telephone service. True or False? ______

Chapter 18

1. The coaxial cables used to transport the desired signals in all cable systems are also employed to supply operating voltage to all amplifiers within that coaxial cable system. True or False? ______
2. All devices in all coaxial systems pass operating power through them to all device output ports. True or False? ______
3. The amplifiers in coaxial cable systems that do pass operating power actually have two or three independent transmission paths through them; two if in a one way system, and three if in a two way system. The additional transmission path is provided for 60 Hertz transmissions alone. True or False? _______
4. The separate transmission path for 60 Hertz is provided through the use of filters. True or False? ______
5. Most cable systems supply operating power as well as desired signals to every service drop. True or False? ______
6. Most cable systems supply operating power as ______.
    a) 120 Hz, 90 Volts
    b) 60 Hz, 60 Volts
    c) 60 Hz, 90 Volts
    d) 60 Hz, 30 Volts
7. Periodically, throughout a coaxial cable system, power supplies are installed which connect to commercial power and insert operating power into the coaxial plant itself. True or False? ______
8. Power supplies in each amplifier in a coaxial cable system accept, regulate, and apply directly to the active or gain modules 60 Hz voltage. True or False? ______
9. Most amplifier gain modules operate on Direct Current, not Alternating Current. True or False? ______

10. The voltage as applied to the coaxial plant for operating power does not suffer any drop in Voltage level from the current drawn through that section of the plant, or from the coaxial cable lengths and resistance involved. True or False? ______

11. The formula from Ohm's Law which is used to calculate the Voltage drop through a portion of a coaxial cable system is ______.
    a) $E = I \times R$
    b) $R = \dfrac{E}{I}$
    c) $E = I \times R$
    d) $P = E \times I$

12. If the AC voltage applied across any amplifier falls below a specified level, the amplifier would not go out of regulation and the DC voltage applied to the module itself would not automatically be too low for proper operation. True or False? _____

13. If a line power supply or an amplifier power supply fails, the RF continuity through that section of a system would be interrupted. True or False? ______

14. Line power supply locations must be calculated during the design or layout phase in order to supply sufficient Voltage to all units powered. True or False? ______

15. Even though a system may not be initially equipped for two-way service, when calculating system powering, each station should be considered to be fully loaded with all the modules that it is capable of handling. True or False? ______

16. If any system is extended, the powering for such system extensions must be calculated. True or False? ______

17. Directional couplers and splitters in a system generally do not pass operating power. True or False? _____

18. Service may be restored to a system, or to part of a system, by providing AC power from a portable generator to a line power supply. True or False? ______

Chapter 19

1. A coaxial cable may be defined as two metallic conductors, separated by a non-conducting dielectric material, sharing the same axis. True or False? ______

2. Some coaxial cables use air as the dielectric material True or False? ______

3. When air is the dielectric material in a cable, the cable will introduce more transmission losses. True or False? ______

4. Some cables use an air-entraining foam dielectric, and such cables have less transmission loss then air dielectric cables. True or False? ______

5. The size, transmission loss, and cost of the coaxial cables employed has a great deal to do with the cost of any system. True or False? ______

6. As a general rule, larger size cables use more material in their manufacture and thus cost more. True or False? ______

7. Since trunk systems are more extensive in length and in amplifier cascade, to limit the amplifier cascade required, most trunk cable is a larger size, lower-loss cable, and costs more than the cables used in feeder plant. True or False? ______

8. All coaxial cable employed in Cable Television systems, regardless of its size or transmission loss, is 60 Ohm characteristic impedance. True or False? ______
9. Coaxial cable called self-support or figure-eight cable has an integral supporting wire or cable along with the coaxial cable itself. True or False? ______
10. Self-support cable is generally employed in Cable Television systems for trunk plant. True or False? ______
11. The cable "loop" resistance, including the resistance of both the center and the outer conductors, is used to calculate the location and frequency for line power supplies. True or False? ______
12. Cable dimensions, transmission losses, and loop resistance are all provided in the manufacturers specifications for any specific cable. True or False? ______
13. The dielectric material employed in a cable is not a factor in the transmission losses of that cable. True or False? ______
14. The economics of any size or type of coaxial cable are not a function of system layout or design, but are decided beforehand by the system engineer. True or False? ______
15. There are a variety of cable types and sizes available for service drop use. True or False? ______
16. All service drop cables in Cable Television systems are 50 Ohm characteristic impedance. True or False? ______
17. Longer service drops in a system cannot be relieved by any special consideration or treatment during system layout. True or False? ______
18. The selection of cable size and type, including the service drop cables, has a definite impact on the overall cost of a system. True or False? ______

Chapter 20

1. Before satellite program delivery was commonly available, systems had to get all programming either off-air, by microwave feed, or in video tape formats. True or False? ______
2. The signal modulation employed for satellite delivery of television video is the same, that is, it is AM, as the modulation employed in commercial TV broadcasting. True or False? ______
3. We use heterodyne processors for each channel taken off a satellite receiver to process that signal correctly for application to, and inclusion on, coaxial cable Television systems. True or False? ______
4. When we employ a heterodyne signal processor, the input and output video signals to the device are ______.
   a) AM input, AM output
   b) AM input, FM output
   c) FM input, AM output
   d) FM input, FM output
5. The transmissions up to, and down from a satellite feeding Cable Television systems employ AM video modulation. Thus we can use the same heterodyne processors that we might use for off-air TV broadcast signals. True or False? ______

6. If the video modulation on the signal transportation or acquisition system and the signal distribution system to subscribers is different, then we must demodulate and remodulate the signal, because the subscriber-owned TV receivers accept and receive AM modulated video. True or False? ______
7. The satellite receivers used in Cable Television systems take in the satellite signal, which employs FM video modulation, and demodulates that signal to provide a video and audio output. True or False? ______
8. The units employed for satellite-delivered signals are ______.
    a) Satellite receiver and heterodyne processor
    b) Pre-amplifier and heterodyne processor
    c) Demodulator and heterodyne processor
    d) Satellite receiver and AM modulator
9. We are obliged to carry all television signals as AM video-modulated and FM audio-modulated on a cable system by the fact that the end devices served, the subscriber television receivers, accept AM video and FM audio. True or False? ______
10. Satellites employed to feed programming to Cable Television systems are positioned about 22,275 miles above the surface of the earth. The satellite thus evidences the same rotational speed as the receiving antenna on the earth's surface, and thus appears fixed in location to that antenna. True or False? ______
11. The down link transmission, from the satellite to the earth, is generally in the 4 gHz (gigaHertz) band. True or False? ______
12. Only one transponder is provided in the satellite to change the frequency of each television signal carried. True or False? ______
13. In a satellite delivering 24 television signals, 12 signals are carried on one antenna polarization, and 12 on another polarization to provide additional isolation of individual signals and increase the satellite transmission capacity. True or False? ______
14. Since earth reception of satellite signals is in the 4 gHz band, low noise preamplifiers are not required or used at the earth satellite receiving station. True or False? ______
15. It is possible for the transported signals received by satellite to be scrambled for the subscribers at the earth receiving station before applying those signals to the local cable distribution plant. True or False? ______
16. It is possible for the transported signals received by satellite to be scrambled for the subscribers at the uplink transmitting station before the signals are sent up to the satellite for relay back down to the individual earth receiving stations. True or False?______
17. Very few Cable Television systems receive any of their programming from satellites today. True or False? ______
18. Satellite reception is possible almost anywhere in the United States for Cable Television service. True or False? ______

Chapter 21

1. The system Head End is where all television signals are processed and prepared for application to the cable system for transportation out to all subscribers.
   True or False? ______

2. In some systems, demodulators are used to break signals down to video and audio, and companion modulators are used to modulate the system RF carrier for that channel. Some or all off-air channels may be processed with back-to-back demods and mods.
True or False? ______
3. Back-to-back demods and mods are not used for satellite delivered channels. A satellite receiver in conjunction with a modulator is actually used instead.
True or False? ______
4. Heterodyning is the process whereby any carrier or a group of carriers is beat against a local oscillator to change the frequency of that carrier or group of carriers.
True or False? ______
5. There is no recommended depth of modulation for heterodyne processors.
True or False? ______
6. heterodyne processors may be used to process satellite-delivered television signals.
True or False ______
7. Demodulators do not accept an audio and video input for processing.
True or False? ______
8. Off-air signals may be processed by a heterodyne processor at system Head Ends.
True or False? ______
9. Whether processed by receiver-modulators, demod-mod combinations, or heterodyne processors, all Head End signals are combined as RF carriers and applied to the same coaxial cable for transportation to subscribers. True or False? ______
10. Preamplifiers are used for off-air signals at Head Ends to improve the C/N Ratio of the signal. True or False? ______
11. Pilot tones for cable system regulation are usually separate signal generators at a system Head End, and such carriers are not usually employed for the transmission of subscriber viewed television signals. True or False? ______
12. In a well designed Head End, significant isolation is provided for low-level signal inputs to devices and high-level signal outputs. True or False? ______
13. Directional couplers are sometimes used to combine television signals at the Head End.
True or False? ______
14. In two-way operations, the Downstream spectrum must be separated from the Upstream spectrum at the Head End. True or False? ______
15. Satellite signals need not be demodulated and remodulated at Head Ends before they are placed on the outgoing coaxial cable itself. True or False? ______
16. A Test Point for test signal insertion into the system is often incorporated into Head End designs. True or False? ______
17. The Head End may be used as a location for a system line power supply, and 60 Hertz, 90 Volts may be coupled onto the coaxial cable to subscribers. True or False? ______
18. In newer systems incorporating optical fibers plus limited coaxial cable plant, a number of small systems may be the result, with each individual fiber-fed common system signals at the Head End. True or False? ______
19. All Head Ends should include a log sheet showing transmitted signal levels on all channels carried. True or False? ______

20. Adjustments on individual signal levels at a Head End should not be indiscriminately made by unauthorized or inexperienced people. True or False? ______

Chapter 22

1. Sometimes it is desirable to transport television signals locally from one Central point to several other points to feed sections of coaxial cable plant. True or False? ______
2. One method of signal transportation is by radio at microwave frequencies. True or False? ______
3. Transportation systems do not feed signals directly to subscribers and their noise and intermod contributions must be combined with that of the cable distribution plant itself. Thus most transportation systems are designed quite conservatively and cost is only one factor, the noise and distortion contributions is certainly another. True or False?______
4. Microwave systems require line-of-sight transmission paths. True or False? ______
5. In single-channel microwave links, the video and audio information need not be modulated onto the microwave carrier itself. True or False? ______
6. The AML type of microwave system does not require any modulation or demodulation process at all, and is best suited when several channels are to be transported and/or several receiving sites are involved. True or False? ______
7. Lightwave transmissions on optical fibers certainly lend themselves well to Cable Television transportation systems. True or False? ______
8. In lightwave transportation systems, we can digitalize each individual signal and integrate these digital pulse streams into one massive, higher bit rate, pulse stream for application to the lightwave system. This is usually what is done in Telephone systems. True or False? ______
9. In lightwave systems, we can also operate the link on an analog basis and simply pass on to this system all broadband RF signals from any Head End just as we do with coaxial cable. True or False? ______
10. The basic advantage of operating a lightwave link on a broadband, analog basis is its compatibility with any other broadband system. We can, for example, easily and inexpensively transpose from an optical fiber link to an RF coaxial cable extension and extend these same signals to subscribers for use. True or False? ______
11. Using an AML type of microwave system, multi-channel transportation is both technically practical and widespread within the Cable Television industry. True or False? ______
12. The lightwave receivers used to feed coaxial extensions of cable systems are strand-mounted and cable-powered, just as the coaxial RF amplifiers themselves. This makes lightwave very readily incorporated into hybrid cable systems. True or False? ______
13. In most hybrid cable systems today, employing both optical fibers and coaxial cable, the lightwave links are operated as analog systems on a broadband basis. True or False? ______
14. Although it is possible to digitalize television signals, and to even combine several such digitalized signals into one higher bit rate pulse stream, this is not done widely in the Cable Television industry today. True or False? ______

15. There is some misunderstanding in the Cable industry between digitalizing one signal and multiplexing several digitalized signals into one pulse stream. We can digitalize any telephone, data, or television signal, and this will result in a single pulse stream for transmission. We can also incorporate by digital multiplexing, a number of such individual signals into a single, higher bit rate, pulse stream. We should not confuse the two processes. True or False? ______
16. For transportation, or for distribution, we can digitalize any individual television signal and use the pulse stream to modulate a discrete RF carrier. This carrier can be combined with other carriers on a cable system using frequency separation, just as we could combine AM and FM modulated carriers on the same system. True or False? ______
17. The decision to incorporate a microwave or lightwave transportation system into a cable operation is more a business or economic judgement than an engineering problem. True or False? ______
18. Microwave systems require some form of Federal license since these signals are radio broadcasts in the public spectrum and in free space. True or False? ______
19. Lightwave links are closed circuit systems just as coaxial cables are, and thus do not require any Federal licensing. True or False? ______
20. The extension of analog, broadband transmission, as employed in coaxial cable television systems today, if naturally and logically pursued, leads to the use of optical fibers in an analog, broadband mode. One might say that optical fiber transmission is simply a logical extension of RF broadband transmission on coaxial cables. True or False? ______

Chapter 23

1. Light can be completely and satisfactorily explained as a system of particles. True or False? ______
2. A photon has a measurable mass. True or False? ______
3. Light energy travels in a wavefront. True or False? ______
4. The wavelength of an alternating wave is the distance it travels in one half a cycle. True or False? ______
5. We can state the wavelength of a signal in units of measure of length with no regard for the medium that the wave is propagating in. True or False? ______
6. Within the same medium, all lightwave frequencies will travel at the same speed. True or False? ______
7. A lightwave signal with a wavelength of 800 nanometers could be a higher frequency signal than one with a wavelength 1,300 nanometers. True or False? ______
8. A nanometer is one billionth of a meter. True or False____
9. All lightwave frequencies employed in a practical lightwave system today are within the visible light spectrum. True or False? ______
10. Light is a form of energy, and as such can be converted to other forms of energy. True or False? ______
11. When light impinges on some materials, those material give off electrons. True or False? ______
12. If we isolate and examine a single discrete frequency of light within the visible spectrum, it will appear to be a specific color. True or False? ______

13. When impinging light is reflected by a smooth surface, the angle of incidence is twice the value of the angle of reflection. True or False? ______
14. The attenuation of light as it propagates through a medium is primarily due to fluorescence. True or False? ______
15. The term "shortwave" came into common usage to denote lower frequencies where the wavelengths were actually shorter. True or False? ______
16. "White" light includes all the visible wavelengths of light. True or False? ______
17. Light is kinetic energy. True or False ______
18. Light can be identified within the general electromagnetic spectrum. True or False? ______
19. Electromagnetic waves, including lightwaves, travel at a speed of 186,280 miles per second in a vacuum. True or False? ______

Chapter 24

1. The level of illumination of a surface by a light source is constant regardless of how distant the light source is from the surface. True or False? ______
2. Color is a physical characteristic of a substance or material. True or False? ______
3. Monochromatic means having or exhibiting more than one lightwave frequency present. True or False? ______
4. Incandescence means the emission of radiation by a hot body that makes it visible. True or False? ______
5. Light scattering is experienced as lightwave energy travels in a vacuum. True or False? ______
6. When the atoms of a material which incident light impinges upon have their energy level raised to the point that they, in turn, emit lightwave energy at the same frequency as the impinging light, this is called absorption. True or False? ______
7. The primary causes of the attenuation of light in air, or in any other medium, are incandescence and fluorescence. True or False? ______
8. Radiant energy is energy traveling in the form of electromagnetic waves. True or False? ______
9. The unit of measure of radiant energy as lightwaves is the Watt. True or False? ______
10. Some devices that measure radiant energy at lightwave frequencies count the number of photons impinging on the photosensitive material of the device. True or False? ______
11. A ratio is the relation in degree or number between two dissimilar things. True or False? ______
12. A common term to denote the power ratio of two levels of lightwave energy is the decibel. True or False? ______
13. We can denote the loss of any particular transmission medium, such as an optical fiber, of a given length, in decibel-milliwatts. True or False? ______
14. The shorter wavelengths (blue is a short wavelength) are more effectively scattered than the longer wavelengths. True or False? ______
15. Light can be generated, propagated, and detected. True or False? ______
16. Light cannot be modulated with intelligence. True or False? ______

17. Both visible and non-visible light can be measured. Light is measured as power, and units of power such as the Watt are used. True or False? ______
18. If the atoms of a substance that light impinges on retain the energy, converting it to heat, the process is called absorption. True or False? ______

Chapter 25

1. A light source that emits a less divergent beam of light will couple less light into a fiber. True or False? ______
2. The efficient transfer of light energy between two fiber ends depends to some degree on the numerical aperture of both fibers. True or False? ______
3. In a digital application, intelligence can be modulated onto a light source by turning the light on or off, or by turning the intensity of the light higher or lower. True or False? ______
4. Modal dispersion is more prevalent in single-mode fiber than in multi-mode fiber. True or False? ______
5. When light passes from a less dense medium to a more dense medium, the velocity of transmission decreases, that is, the light travels at a slower speed in the more dense medium. True or False? ______
6. A step index fiber will have a distinct transition between the core and cladding refractive indexes. True or False? ______
7. The numerical aperture of a fiber denotes the maximum angle of light entering the end of the fiber that will be propagated within the core material of the fiber. True or False? ______
8. Graded index fibers depend upon the reflective optical mechanism of the fiber to minimize pulse dispersion. True or False? ______
9. Light energy propagates through a single mode fiber reflectively. True or False? ______
10. The mode field diameter is the diameter of the core material in the fiber. True or False? ______
11. The small physical dimensions of multi-mode fibers used in telecommunications systems are dictated by the need to ensure total internal reflection within the fiber. True or False? ______
12. Smaller numerical apertures make it more difficult to couple light energy into fiber. True or False? ______
13. Single mode fibers present more bandwidth for transmission use than graded index fibers do. True or False? ______
14. The usable transmission bandwidth that a fiber presents has no relationship to the digital transmission data rate that the fiber can support. True or False? ______
15. If the changes in the refractive index through the cross section of a fiber have distinct transitions, the fiber has a step index structure. True or False? ______
16. In a graded index fiber, all light energy propagates through the fiber core. True or False? ______
17. A single mode fiber is a step index structure. True or False? ______

18. In a single mode fiber, a significant amount of light energy actually propagates through the cladding material. True or False? ______

Chapter 26

1. Optical fibers function as waveguides for light energy. True or False? ________
2. Light scattering in optical fibers is largely due to reflections within the fiber itself. True or False? ________
3. We expect, and always experience, lower fiber losses at longer wavelengths of light. True or False? _______
4. Lower fiber loss at longer light wavelengths is due to the light scattering within the fiber itself. True or False? _______
5. The high attenuation peaks in a fiber at some lightwave frequencies is the result of some foreign elements or impurities within the glass itself.True or False? ______
6. The term "first" and "second" windows refer to those sections of the spectrum of an optical fiber where the light energy losses are the greatest. True or False? ______
7. Mechanical irregularities between the cladding and the core material have no effect on optical fiber transmission loss. True or False? _______
8. Loss, in optical fibers, refers to the attenuation of light energy as it passes through the fibers, regardless of the cause. True or False? _______
9. In single mode fibers, loss is usually expressed as dBm. True or False? _______
10. Transmission levels in an optical system may be expressed as decribed (dB). True or False? _______
11. Intersymbol interference in digital links is the result of pulse broadening. True or False? ______
12. The fiber attenuation curve of any fiber depends upon the material with which the fiber was fabricated. True or False? ______
13. The process of adding different materials in the fabrication of fiber glass is called "doping." True or False? ______
14. Light absorption in optical fibers is not a function of the impurities in the glass material itself. True or False? ______
15. In a single-mode fiber, if the overall desired length of the link is known, the overall link loss can be determined by multiplying the fiber loss per kilometer by the link length in kilometers. True or False? ______
16. Given lightwave transmitter output in dBm, and fiber loss in dB, lightwave receiver input level in dBm is derived by subtracting the loss in dB from the level in dBm. True or False? _____
17. Fiber link performance in analog systems is specified as Bit Error Rate (BER). True or False? ______
18. There is no correlation between bandwidth and Rise Time. True or False? ______
19. In single mode fiber, a specification to produce 250 mHz of usable bandwidth per fiber kilometer will provide _______ mHz of usable bandwidth overall in an 5 kilometer link.
    - a) 20 mHz
    - b) 50 mHz
    - c) 200 mHz
    - d) 500 mHz

20. Lightwave links may be analog or digitally modulated. True or False? ______

Chapter 27

1. An optical device is a unit, or an assembly of optical components, whose basic function derives from optical principles or mechanisms. True or False? ______
2. Optical switches can be fabricated by mechanically altering the physical relationship of prisms or the ends of fibers. True or False? ______
3. A diffusion grating involves the use of optical prisms. True or False? ______
4. Lenses may be incorporated into practical optical devices. True or False? ______
5. Mirrors are not often employed in optical devices. True or False? ______
6. Glass fibers can be fused together in the fabrication of optical devices. True or False? ______
7. Lightwave systems can be tapped at RF at many, randomly located places along the system for direct subscriber service. True or False? ______
8. For various services, and for shorter lengths, optical fibers can be fabricated from plastic materials. True or False? ______
9. When cabling optical fibers, we need not consider the transfer of mechanical stress to the fibers themselves. True or False? ______
10. Macro-bending occurs when a fiber bend radius decreases to the point that light rays within the core material escape into the cladding material. True or False? ______
11. Optical fibers are usually cabled together as bare glass structures, and no individual fiber protection is generally provided. True or False? ______
12. Ribbon cable structures find their greatest use when fiber counts are 8 fibers or less. True or False? ______
13. "Strength members" are sometimes used to provide cable rigidity and mechanical strength to cable structures. True or False? ______
14. Optical fibers must always be fused together to provide an acceptable splice. True or False? ______
15. The "figure eight" configuration is often used during construction to provide temporary storage for fiber cable and to reduce the length of cable pulls, or the number of required splices. True or False? ______
16. Optical cables always require some metallic cable element. True or False? ______
17. Electrical bonding to other plant is primarily a function of protecting personnel and plant. True or False? ______
18. Optical cables cannot be directly plowed underground. True or False? ______
19. Optical cables cannot be lashed to existing aerial cables. True or False? ______
20. Optical cables are relatively immune to electromagnetic interference from electrical induction. True or False? ______

Chapter 28

1. In hybrid Cable Television systems, paralleling optical fibers are often, if not usually, required. True or False? ______
2. A single fiber in a hybrid system is usually required to serve 10 or 15 coaxial cable extensions. True or False? ______

3. If, in a hybrid system, a single lightwave transmitter fails, all system subscribers service is interrupted. True or False? ______
4. Two way transmission on any lightwave link of a hybrid system is not possible. True or False? ______
5. Return or upstream transmission in a hybrid system may be provided by a separate optical fiber from every system node. True or False? ______
6. WDM is the abbreviation for Wavelength Division Multiplexing. Essentially this is the same separation of spectrum that we use in two-way coaxial cable plant except that in this case, the spectrums separated are all at lightwave frequencies. True or False? ______
7. Lightwave transmitters produce the same transmission performance regardless of the number of television channels they may be carrying. True or False? ______
8. We can ensure that lightwave receiver input levels are the same in different length fiber links by using the same transmitter output in all cases, and simply optically attenuating or padding down the lightwave input to each receiver as necessary. True or False? ______
9. We can adjust for different link lengths by using the same receiver at all locations, and using lightwave transmitters with different outputs as necessary. True or False? ______
10. In hybrid systems, coaxial cable extensions are not limited in length to any specific number of RF amplifiers. True or False? ______
11. Optical fiber losses are stated in dBm. True or False? ______
12. Fiber connectors, which allow fiber disconnect and reconnect, have less loss than fusion splices or mechanical splices. True or False? ______
13. Both lightwave link and coaxial cable extensions in a hybrid system, have their individual transmission performance stated in common terms and units, and overall performance is a combination of the two. True or False? ______
14. Hybrid systems are easier to engineer and predict performance for. True or False? ______
15. The long term maintenance of hybrid systems is more sophisticated and difficult than for all-coaxial systems. True or False? ______
16. The reliability of service to subscribers is not increased by hybrid systems when they are compared to all-coaxial cable systems. True or False? ______
17. A hybrid system actually consists of a number of small, technically independent systems with each consisting of optical fiber, followed by some coaxial cable, to serve a limited number of subscribers. True or False? ______
18. In hybrid systems, the selection of subscriber tap values in the coaxial extensions requires special engineering. True or False? ______
19. Hybrid nodes are intentionally limited to serve a specific number of subscribers. In establishing such nodes however, a single lightwave transmitter may serve only one lightwave receiver and its associated coaxial extension, or it may serve two or more receivers with their associated coaxial extensions. True or False? ______
20. The quality of the television pictures presented to each subscriber will always be somewhat poorer in any hybrid system, as compared to any all-coaxial system. True or False? ______

Chapter 29

1. Transmission "Quality Assurance" in any system should be considered as an essential part and a natural extension of all long term maintenance programs. True or False? ______
2. Proof-of-performance tests on new plant, or new plant additions, justifies and requires a higher level of performance testing than may be necessary or required of routine maintenance programs. True or False? ______
3. All personnel, or at least all even marginally qualified personnel, should regularly be exposed to some level of routine testing to familiarize themselves with normal system operation. True or False? ______
4. System Head Ends should have output to the system test points clearly and conspicuously identified, and normal signal levels at those test points should also be prominently displayed. True or False? ______
5. It is not necessary, when performing routine maintenance test, to record either the time of day or the outside temperature. True or False? _______
6. Permanent system test points are not particularly useful in maintaining or restoring systems. True or False? ______
7. Permanent test points for routine and repeated tests, should be located to provide maximum safety for vehicles and personnel, even under reduced visibility or inclement weather conditions. True or False? ______
8. There is no practical possibility of fixed gain or pre- adjusted replacement equipment in either all-coaxial or hybrid systems. True or False? ______
9. The objective for all maintenance programs is, or should be, the repeatability by different personnel of any and all routine tests. True or False? ______
10. More sophisticated tests, performed on a routine basis by select, highly qualified personnel, is the best and only maintenance program for all systems. True or False? ______
11. Complicated or sophisticated test equipment and procedures should only be utilized by qualified personnel. Sophisticated test of themselves do not automatically ensure more, or more essential, information. True or False? ______
12. It is not necessary to periodically calibrate all system Signal Level Meters (SLM's). True or False? ______
13. On a routine basis, lightwave links should always be checked for lightwave signal level input to receivers, even if this requires dis-connection and re-connection of the optical fiber at that point. True or False? ______
14. Few if any of the generally accepted and applied tests for all-coaxial cable systems will find applications in hybrid systems. True or False? ______
15. RF signal levels in any system should not simply be referred to or recorded as decibels (dB). True or False? ______
16. Equipment adjustment after service restoration replacement should not be indiscriminate, or considered as final, unless those adjustments are performed by fully qualified personnel. True or False? ______
17. Subscriber service complaints have little value in maintaining system transmission quality. True or False? ______

18. All reports of "No trouble found" made by service personnel should be suspect, and subjected to further review and analysis. True or False? ______
19. Routine maintenance test should be simple and easily repeated by others, and should be within the technical capability of most, or all, servicing personnel.
True or False? ______
20. Hybrid systems do not automatically escalate the level of routine maintenance tests.
True or False? ______

Chapter 30

1. Terminal equipment may in some cases include subscriber taps, but as a general rule, such equipment and devices are confined to those within the subscriber premises.
True or False? ______
2. Standard terminal equipment is taken to mean that which is required and supplied at all subscriber installations. True or False? ______
3. The physical grounding of the coaxial outer conductor at subscriber premises is required by the National Electrical Code. True or False? ______
4. Splitters and couplers are used at subscriber stations as required, and all such splitters and couplers pass AC power just as their counterparts out in the cable plant do. True or False? ______
5. Matching transformers are used at all subscriber-owned television receivers whether they are 300 Ohm devices or 75 Ohm devices. True or False? ______
6. Subscriber taps are considered active units and require operating power when they perform such functions as remote addressability, remote disconnect or reconnect, or any level of signal de-scrambling. True or False? ______
7. When dual cable systems are tapped for service, two parallel service drops are provided and the subscriber manually switches from one cable to the other with an A-B Switch, located at the subscribers TV set. True or False? ______
8. Tunable RF converters usually have one RF output on standard TV Channel 3 or 4, which is fed to the subscriber-owned TV set. The TV set is not tuned to other channels, and the subscriber normally does all channel selection by tuning this converter alone.
True or False? ______
9. Cable Television grounding blocks provide electrical connection to the outer conductor of the coaxial cable alone, and do not provide access or electrical connection to the inner conductor at all. True or False? ______
10. Exclusion traps may be electrically located at either end of a subscriber drop, but such traps are usually located off-premises at the system end of the drop to discourage subscriber tampering with such devices. True or False? ______
11. When a cable system carries any RF signals that the subscriber TV set cannot tune, some conversion of some or all RF carriers is necessary. True or False? ______
12. The term "cable-ready TV set" applies to commercially available TV receivers that do not tune any non-broadcast standard television carriers. True or False? ______
13. "Scrambling" is a term that refers to any method of distorting or encoding a TV signal such that unauthorized subscribers may not view it. It does require that some form of de-scrambling at the authorized subscribers sets must be provided. True or False? ______

14. Addressability refers to the mail that is sent out to accomplish subscriber billing for monthly service. True or False? ______
15. Service drop cables to private homes are usually RG-59 or RG-8, but in some cases may be RG-11. True or False? ______
16. Service drop cable of any size is not available in a self- support structure. True or False? ______
17. The standard type of service drop and inside cable fitting for connection is called a “B” fitting. True or False? ______
18. RF converters for use at subscriber receivers generally receive their operating AC power over the cable system service drops themselves. True or False? ______

Answers Tabulated

We have prepared and offer two sets of answers. The first set includes answers only for the convnience and facility of the users in marking examinations rapidly.

The second set contains those same answers but offers a brief explanation of each when appropriate. Some answers are absolute and require no explanation. In some cases, a previous answer and explanation may be useful, and reference to that answer is made. These explanations may be helpful to group instructors or to further the understanding of individual students.

Some Chapters, due to the nature of the material covered and it's sophistication, do not lend themselves to questions and answers, and in those cases none were prepared or are offered.

Chap 1	Chap 2	Chap 3	Chap 4	Chap 5	Chap 6
1 F	1 T	1 C	1 F	1 T	1 F
2 T	2 T	2 T	2 T	2 F	2 T
3 T	3 F	3 D	3 T	3 T	3 F
4 T	4 F	4 T	4 F	4 T	4 T
5 T	5 F	5 F	5 T	5 T	5 T
6 F	6 F	6 F	6 T	6 A	6 T
7 C	7 T	7 T	7 C	7 F	7 F
8 D	8 T	8 F	8 C	8 T	8 T
9 F	9 F	9 A	9 T	9 D	9 F
10 F	10 T	10 T	10 T	10 C	10 B
11 F	11 T	11 T	11 D	11 F	11 T
12 F	12 C	12 F	12 C	12 D	12 T
13 T	13 B	13 F	13 C	13 F	13 C
14 T	14 T	14 F	14 B	14 F	14 F
15 F	15 B	15 T	15 F	15 C	15 T
	16 T	16 F	16 T	16 T	16 F
	17 T		17 T	17 T	17 B
	18 F		18 T	18 B	18 T
	19 F		19 F	19 F	19 F
	20 T		20 F	20 T	20 F

Chap 7	Chap 8	Chap 9	Chap 10	Chap 11	Chap 12
1 T	1 F	1 F	1 F	1 T	1 T
2 T	2 T	2 T	2 F	2 T	2 T
3 F	3 T	3 T	3 T	3 T	3 F
4 C	4 F	4 F	4 T	4 F	4 F
5 T	5 T	5 F	5 T	5 T	5 T
6 F	6 F	6 F	6 F	6 F	6 F
7 T	7 T	7 T	7 F	7 C	7 F
8 T	8 F	8 T	8 A	8 T	8 F
9 F	9 F	9 T	9 F	9 T	9 T
10 T	10 T	10 F	10 T	10 T	10 F
11 F	11 T	11 F	11 T	11 T	11 D
12 F	12 T	12 T	12 T	12 T	12 T
13 D	13 T	13 F	13 F	13 F	13 C
14 F	14 C	14 A	14 F	14 F	14 T
15 T	15 F	15 F	15 T	15 T	15 T
16 T	16 B	16 T	16 T	16 T	16 F
	17 T	17 T			17 F
		18 T			18 T
					19 F
					20 F

Chap 13	Chap 14	Chap 15	Chap 16	Chap 17	Chap 18
1 T	1 T	1 T	1 T	1 T	1 T
2 T	2 T	2 F	2 T	2 T	2 F
3 T	3 F	3 T	3 T	3 T	3 T
4 T	4 T	4 T	4 F	4 T	4 T
5 T	5 F	5 T	5 F	5 B	5 F
6 B&C	6 T	6 A	6 T	6 T	6 B
7 T	7 F	7 F	7 T	7 T	7 T
8 D	8 F	8 F	8 F	8 F	8 F
9 B	9 F	9 F	9 T	9 T	9 T
10 F	10 F	10 A&D	10 T	10 D	10 F
11 T	11 F	11 C	11 T	11 T	11 C
12 F	12 F	12 F	12 T	12 F	12 F
13 T	13 A	13 A&D	13 F	13 F	13 T
14 T	14 T	14 T	14 F	14 A&C	14 T
15 T	15 C	15 T		15 T	15 T
	16 T	16 T			16 T
	17 T				17 F
	18 F				18 T
	19 T				
	20 T				

Answers Tabulated

Chap 19	Chap 20	Chap 21	Chap 22	Chap 23	Chap 24
1 T	1 T	1 T	1 T	1 F	1 F
2 T	2 F	2 T	2 T	2 T	2 F
3 F	3 F	3 T	3 T	3 T	3 F
4 F	4 A	4 T	4 T	4 F	4 T
5 T	5 F	5 T	5 F	5 F	5 F
6 T	6 T	6 F	6 T	6 F	6 F
7 T	7 T	7 T	7 T	7 F	7 F
8 F	8 D	8 T	8 T	8 T	8 T
9 T	9 T	9 T	9 T	9 F	9 T
10 F	10 T	10 T	10 T	10 T	10 T
11 T	11 T	11 F	11 T	11 T	11 F
12 T	12 F	12 T	12 T	12 T	12 T
13 F	13 T	13 T	13 T	13 F	13 F
14 T	14 F	14 T	14 T	14 F	14 T
15 T	15 T	15 F	15 T	15 F	15 T
16 F	16 T	16 T	16 T	16 T	16 F
17 F	17 F	17 F	17 T	17 T	17 T
18 T	18 T	18 T	18 T	18 T	18 T
		19 T	19 T	19 T	
		20 T	20 T		

Chap 25	Chap 26	Chap 27	Chap 28	Chap 29	Chap 30
1 T	1 T	1 T	1 T	1 T	1 T
2 T	2 F	2 T	2 F	2 T	2 T
3 T	3 T	3 F	3 F	3 T	3 T
4 F	4 T	4 T	4 F	4 T	4 F
5 T	5 T	5 F	5 T	5 F	5 F
6 T	6 F	6 T	6 T	6 F	6 T
7 T	7 F	7 F	7 F	7 T	7 T
8 F	8 T	8 T	8 T	8 F	8 T
9 F	9 T	9 F	9 T	9 T	9 T
10 F	10 F	10 T	10 F	10 F	10 T
11 T	11 T	11 F	11 F	11 T	11 T
12 T	12 T	12 F	12 F	12 F	12 T
13 T	13 T	13 T	13 T	13 F	13 T
14 F	14 F	14 F	14 T	14 F	14 F
15 T	15 T	15 T	15 F	15 T	15 T
16 T	16 T	16 F	16 T	16 T	16 F
17 T	17 F	17 T	17 T	17 F	17 F
18 T	18 F	18 F	18 F	18 T	18 F
	19 B	19 F	19 T	19 T	
	20 T	20 T	20 F	20 T	

Answers Explained

Chapter 1

1. False Cable Television systems employ Amplitude Modulation (AM) for video carriers and Frequency Modulation (FM) for audio carriers.
2. True Some coaxial cable Cable Television systems have bandwidth all the way up to 800 mHz and higher, and such systems could actually carry some signals in the commercial broadcast UHF band.
3. True Microwave frequencies are higher in frequency than Radio and TV frequencies, and are lower in frequency than lightwave frequencies.
4. True All radio, sound, and lightwaves are Alternating Currents and travel in a wavefront.
5. True The physical wavelength of alternating signals at higher frequencies are shorter.
6. False Although coaxial cable systems are closed, and thus do present significant bandwidth for private allocation or use, since no public spectrum as in free space is utilized, no Federal licensing of individual signals or carriers is required.
7. C Standard commercial broadcasting television carriers do, for all practical purposes, occupy 6 mHz of spectrum for each such signal.
8. D All commercial broadcasting television stations employ Amplitude Modulation (AM) for video or picture carriers.
9. False Broadcast television signals are vestigal side band, and only one full side band of a modulated signal is actually transmitted. To interface with subscriber owned television receivers, the cable modulators employed by Cable Television systems are also vestigal side band units.
10. False In Cable Television systems, transmission from the Head End out to all subscribers is generally referred to as "downstream" transmission, and beck from the subscribers to the Head End is generally referred to as "upstream."
11. False A Mid-Split system is not generally employed for conventional Cable Television service but is usually employed in business, commercial, or industrial service, thus such systems do not generally carry standard television signals on Channels 2 through Channel 6.
12. False Any coaxial cable, and any optical fiber for that matter, can, by judicious use of separation of transmitted frequencies, be employed in bi-directional or two way transmission.
13. True Transmission frequencies and cable losses are such that frequent reamplification, as often as three or more amplifiers per mile of coaxial cable, are commonly required.
14. True The larger the size of a coaxial cable, the less transmission loss it will introduce to any fre-

quency passed through it.

15. False Unity gain is a term describing operation of a section of transmission plant that overcomes or offsets all transmission losses within that section with equal transmission gain.

Chapter 2

1. True In any transmission system we must address these two factors, loss and gain, as basic factors and considerations. There may be, and certainly are, other factors such as distortion for example, but these two cannot be ignored in any case.

2. True We must actually calculate the transmission levels as presented to each and every individual subscribers premises in order to assure that all devices at that station, which includes subscriber owned television receivers of course, are presented with adequate signal levels to insure their proper operation.

3. False The decibel only denotes a ratio between two quantities and cannot, by itself, denote any individual level of signal. The dBmV, on the other hand, can denote any individual signal level and may not, of itself, be used to denote specific loss or gain which are, of course, ratios between inputs and outputs, two different quantities.

4. False The decibel must be used to denote the ratio between two different quantities or levels of signal, and an amplifiers gain is the difference between its input signal level and its output signal level, and these are two different levels are they not?

5. False To denote any single, specific level or quantity of signal, a ratio as denoted by the decibel may not be used. A ratio, by definition, is the relation in degree or number between any two similar things.

6. False By definition, a decibel is one tenth of a Bel. One Bel, by definition, is a ratio of 10 to 1 of two discrete power levels.

7. True Yes, since these ratios may be used to denote either gain or loss, the distinction would be as a negative or positive value. An amplifier may have a gain of + 10 dB and a length of cable loss of - 10 dB.

8. True Since the Bel is defined as a ratio between two power levels, and since the decibel is merely a fraction of a Bel (1 tenth), there certainly is a definite relationship.

9. False Bels and decibels are logarithmic.

10. True All numbers, negative or positive in value, have a logarithm and these may be found in log tables in any mathematics book, on a slide rule, or displayed on any scientific calculator.

11. True The number 1,000 may be written 10^3 without changing its value at all. In this notation, the numeral 3 is the exponent. If we denote this number in another way, we might write it 10 x 10 x 10, which is the number 10 multiplied by itself three times. In this case, the exponent 3 is actually the logarithm of the number 1,000.

12. C The correct formula to determine the ratio in decibels between any two power levels is

$$dB = 10 \log \frac{P_2}{P_1}$$

13. B We can develop this mathematically from the formula as follows:

$$dB=10 \log \frac{P_2}{P_1}$$

$$dB=10 \log \frac{3000}{300}$$

$dB= 10 \log$ (log of 10 is 1)

$dB=10 \times 1$

$dB=+ 10dB$

14. True We can develop this mathematically from the formula as follows:

$$dB=10 \log \frac{P_2}{P_1}$$

$$dB=10 \log \frac{50}{100}$$

$$db=10 \log \frac{1}{2}$$

$dB = -10 \log 2$ (log of 2 is .3)

$dB = -10 \times .3$

$dB = -3\ dB$

15. B We can denote one millivolt across 75 Ohms, which is the value of 0 dBmV by definition, as 10^{-3} Volts across 75 Ohms.

16. True We can develop this mathematically from the formula as follows:

dBm = 1 milliwatt or .001 watts
dBmV = $.0133 \times 10^{-6}$ watts
then

$$dB=10 \log \frac{P_2}{P_1}$$

$$dBmV = 10 \log \frac{.001}{.0133 \times 10^{-6}}$$

$dBmV = 10 \log (7.5188 \times 10^{4)}$

$dBmV = 10 \times 4.876$

$dBmV = +48.76\ dBmV$

17.	True	Assuming an input signal level of +12 dBmV and an amplifier gain of 22 dB, an amplifier would have an output signal level of +34 dBmV. Assuming +34 dBmV input signal level to a length of cable with a loss of 22 dB, the output of that length of cable would be +12 dBmV.
18.	False	$E = I^2 \times R$ is not correct. If we solve the Ohms E Law formula $I = \frac{E}{R}$ for the value of E, the correct answer is $E = I \times R$. The Ohms Law formula $E = I^2 \times R$ is actually the formula for power, not Voltage, which reads correctly as $P = I^2 \times R$.
19.	False	Since the term decibel can only denote a ratio between two values or quantities, it cannot correctly be employed to denote an absolute level of power. The other terms, dBmV, watt, and horsepower do denote specific levels of power.
20.	True	If the correct formula for voltage are applied with all measurements given in voltage, or the correct formula for power are applied with all measurements given in power, then the proven results would be the same for a given problem.

Chapter 3

1.	C	The term used to denote a series of amplifiers serially connected, that is, the output of one feeds another, is called a cascade.
2.	True	All amplifiers require some operating power as opposed to subscriber taps, for example, which may be passive in nature and do not require any operating power. Passive devices may consume some signal power due to their individual inefficiency, but this is not the same as operating power applied simply to make such devices work.
3.	D	In a bi-directional amplifier there is one transmission path for downstream from the Head End, there is one transmission path for upstream to the Head End, and there is the third transmission path, often overlooked, for AC power to and through the unit. That is three separate paths through the device.
4.	True	The amplifier operating power as applied to the system and carried over the transmission coaxial cables is 60 Hertz Alternating Current (AC).
5.	False	All two way splitters for example, by definition, divide their input power equally between two out puts and there is no power distribution by splitter value. In effect, all two way splitters would have exactly the same signal output on both output ports. This is not true of directional couplers.
6.	False	Unless specific work operations are performed within the coupler itself, pulling a fuse or cutting out a choke coil for example, line couplers do pass AC power to and from all cable ports.
7.	True	The insertion loss of taps is the same in either direction through the tap, that is, from its Line In to its Line Out. The isolation loss of a tap, normally between the Line Out to the tap ports would now be applied as the tap loss from the Line In to the tap ports. The drop cables, and all subscribers so fed, would experience an unusually low signal level due to this misplaced loss, but down the cable system itself, little effect would be seen.
8.	False	Since taps divert different amounts of signal toward their drops according to their value in dB, then more or less signal may be available at the Line output of the taps for use further down the system. Thus taps of different value may have substantially different insertion losses.

9.	A	The symbol for a 4 port tap is a square, and the numeral inserted within that symbol denotes the tap value in dB. A small circle denotes a 2 port tap and a hexagon an 8 port tap.
10.	True	Active taps do require some operating power. This power may be extended from the subscribers premises up the subscribers drop wire itself.
11.	True	Since no operating power must be passed through such units, they do not generally pass AC power at all.
12.	False	Whatever the band pass capability of a coaxial system is specified to be, all devices in that system which pass system signals must exhibit band pass at least equal to the system specifications.
13.	False	Since the system and thus the Cable Operator is not generally responsible for operating power for any devices within the subscribers premises, for de-scramblers or converters for example, most systems do not pass any AC power through subscriber taps to the drop cable ports.
14.	False	An attenuator or pad is flat in nature, that is, it exhibits the same transmission loss to any frequency passed through it. Thus such a device may be used to control the signal level throughout a system, but it cannot correct for any frequency response that may be introduced into the system.
15.	True	Such devices may have characteristic frequency distortion or ripples in response, and such are sometimes called the signature of those devices.
16.	False	Because the signal levels available at different points in a coaxial cable system are different, and because all subscriber stations must be fed the same signal levels, or nearly so, the values of subscriber taps are required in any system to provide the designer with some control of signal levels for each subscriber premises.

Chapter 4

1.	False	Since we are obliged to specify and prove the performance between the interfaces of the cable transmission system itself, and since the transmission system is concerned entirely with the transmission of modulated carriers, we use the term Carrier-to-Noise (C/N) Ratio instead, as more useful and appropriate.
2.	True	We are addressing only the noise that affects a single television signal. The noise present in say Channel 4 has no significant effect on any noise that might be present in say Channel 8.
3.	True	The actual formula includes bandwidth, the temperature of the device, and an element called Boltzman's constant. If we could refrigerate the unit and keep it cold, we might actually reduce the level of the thermal noise contribution, but this is not practical in cable applications.
4.	False	The term used to denote a specific units noise contribution is called its "Noise Figure" and is specified in Db.
5.	True	If we were addressing or measuring these same signals as video signals, we would use the term Signal-to-Noise (S/N) Ratio. There is a correlation between these two terms, of course.
6.	True	If some signals were presented to each system amplifier at significantly higher levels, they would enjoy a better C/N Ratio, of course, but if we charge the same fees for all signals carried, we cannot favor any particular signals above any others.
7.	C	We cannot reduce the thermal noise and if we cannot change the amplifier itself, we cannot improve its Noise Figure, but we can manipulate the input signal level, and that will improve an amplifier C/N Ratio on a 1 dB for 1 dB basis.

8.	C	If we raise the input signal level the same amount to all system amplifiers, if they are the same and have the same Noise Figure, then the entire system C/N Ratio will improve on a 1 dB per 1 dB basis.
9.	True	Since we are concerned here with only the noise power within the 4 mHz occupied by a single channel, any other noise elsewhere in the spectrum or within any other channel, has no effect at all, be it 10 such channels or 20.
10.	True	With this one figure alone a transmission engineer can develop satisfactory amplifier input levels so as to develop a desired C/N Ratio per amplifier and to extend that to any cascade of such amplifiers.
11.	D	If we double the number of amplifiers and the original quantity introduced a given amount of noise or created a specific C/N Ratio, then when we double that number, we will be effectively introducing that same amount of noise again, which would mean twice as much noise in the resultant cascade as in the original quantity. Twice as much noise power is 3 dB more noise, or a reduction of 3 dB in the ratio between the desired Carrier and the Noise, which is the C/N Ratio.
12.	C	We must calculate the combined C/N Ratio unless the two contributions are equal, in which case we are simply adding the same amount of noise and twice as much noise power would be 3 dB more, of course. We need not actually calculate this, we can use a chart which effectively combines two different C/N Ratios.
13.	C	The correct formula for a single amplifier is: $C/N_{amp} = Sig_{in} + 59 - NF$
14.	B	The correct formula for cascaded amplifiers is: $C/N_{sys} = C/N_{amp} - 10 \log N$
15.	False	Since the housing may include several devices including filters, equalizers, and pads, and since the gain module manufacturer cannot know just how many, or what sort of devices may be included, he must specify the Noise Figure at the input to the gain module itself, his only known point.
16.	True	If the most distant point is taken to be the stated performance, all other points of service may be better but they cannot be worse.
17.	True	The nature of the noise generated within the device is called "white noise" and is assumed to be at the same amplitude across the entire pass band of the unit.
18.	True	There is no ratio between the two levels if they are at the same amplitude and the unit cannot distinguish or discriminate between the desired signal and the noise that is present.
19.	False	Since we are discussing the ratio between two items, the desired signal and the noise power, we must use dB, since this is the correct unit for stating ratios. We cannot use dBmV which is a discrete, single signal level.
20.	False	The figure in a Carrier-to-Noise Ratio denotes the difference in level between the desired signal and the noise. Quite obviously, if the figure is larger, then the difference between the two levels is greater. If the signal level remained constant while the noise level increased, then that would constitute a lower, not higher, C/N Ratio.

Chapter 5

1. True There are several forms of intermodulation distortion but the remedial measures, primarily reducing the number of channels carried or reducing the operating output level, are equally beneficial for all forms of distortion.
2. False Intermodulation is due to the non-linearity of an amplifier and this is aggravated by increasing the composite RF energy passed through the unit.
3. True Since the unit becomes less linear as more RF energy is passed through, and since each additional channel increases the composite RF energy, the number of channels carried is a factor.
4. True Yes, intermodulation is a voltage addition unlike noise, which was a power addition. This accounts for the apparent discrepancies in various formulas where the figure used is 10 log in power calculations and 20 log in voltage calculations. It also accounts for the fact that in C/N calculation, an increase or decrease of input level by 1 dB results in an equivalent 1 dB change in C/N Ratio. In intermod calculations, a 1 dB increase or decrease in output level results in a 2 dB change in the intermodulation distortion.
5. True This is true, and we would expect, with intermod distortion, a 2 dB change for every 1 dB change in output level.
6. A The correct formula for a single amplifier is:
   $XM_{amp} = XM_{spec} + 2(OL_{oper} - OL_{spec})$
7. False The manufacturer has simply identified the output level at which he has measured the reported distortion, along with how many channels were present. You are entirely free to operate at different output levels if you are prepared to accept the resulting distortion contribution.
8. True He must, of course, give you the intermod distortion that was measured, but he must also qualify the conditions under which that measurement was made by including the operated output level and the number of channels carried.
9. D The correct formula for a cascade of units is:
   $XM_{sys} = XM_{amp} + 20 \log N$
10. C Since this is a voltage addition, we would expect that the intermod distortion would increase 2 dB for each 1 dB increase in output level. Since the output was raised 2 dB, the distortion would be raised by 4 dB.
11. False To combine distortion figures, a calculation must be made in every case unless the figures are equal, in which case either figure would degrade by 6 dB since this is a voltage addition. Graphs are available to combine distortion figures and may be used, of course.
12. D If the signals are "tilted" before they pass through the last amplifier stage, it means that some of the lower frequency signals do not actually pass through at all. In effect, we gradually lower the level of signals with the lowest frequencies being attenuated the most. If we do reduce some of the RF carriers in this fashion, we reduce the composite RF energy that must pass through the last stage of amplification, and this, in effect, reduces the load on the amplifier and it functions more linearly, thus it does actually reduce the intermodulation contribution somewhat.

13. False To specify the intermodulation distortion adequately, the manufacturer does have to call out the channel loading when the tests were done, and the output level, and the actual distortion measured, of course, but the Noise Figure is associated with the amplifier input itself, and the C/N Ratios, and has nothing at all to do with the distortion contribution.

14. False The equalizer does tend to offset any discrepancies in signal level before they enter the gain module itself. In effect, all signals enter the gain module at the same level, or as nearly so as possible. But this is done to assure that all signals will enjoy the same C/N Ratio, and has no beneficial advantage for the units intermodulation distortion.

15. C If we decrease the output of any amplifier, or a cascade of similar amplifiers, we improve all forms of distortion. This is on a 2 for 1 basis, so if we decrease the output level of all amplifiers, we do expect the intermod distortion for the cascade to improve or decrease by 2 dB.

16. True We can use charts or graphs to combine both different distortion figures and different C/N figures. This speeds things up and simply eliminates developing a composite result mathematically.

17. True Any remedial measure such as reducing the number of channels carried or reducing the output signal level will have the same remedial effect on all forms of intermod distortion. A unit may have different levels of different forms of distortion, but the corrective action would affect all equally.

18. B Distortion figures that are more negative simply mean the contributed level of the undesired distortion is at a lower level or amplitude, thus the more negative the number, the less offensive the distortion contribution will be.

19. False Since the distortion is a voltage measurement, it changes 2 for 1. If the manufacturer measured a distortion at a given output level, and we increase the output level by 2 dB without changing the number of channels carried, then we expect the measured distortion to increase by 4 dB and have more distortion, not to decrease and have less distortion as this question stated.

20. True This is true, and unlike the single figure Noise Figure, intermodulation distortion specifications are both comprehensive and sophisticated

Chapter 6

1. False Since this is a power addition, not voltage, it reacts 1 for 1, and the end of system C/N Ratio would only be improved or raised by 1 dB.

2. True Raising the input to the cascade, if all gain stay the same, would raise all amplifier inputs and outputs throughout the cascade, and would change the end of system transmission performance.

3. False Although we would change all amplifier operating levels, and thus we would change the system transmission performance, since we have not changed the amplifier gain and thus the amplifier spacing, we would not change the economics of the system as the question stated.

4. True Since the intermod of an amplifier is a function of the composite RF energy passed through it, or the number of channels of course, the measured intermod that the manufacturer specifies is only valid for that particular channel loading.

5.	True	This is so because although we can change the system performance by changing transmission levels alone, we would not change the amplifier spacing unless we change the amplifier gain. The amplifier spacing dictates the number of amplifiers used per mile of plant, and this surely affects the system cost.
6.	True	The gain of an amplifier does dictate the relationship of noise and intermod at any particular operating levels, thus raising or lowering the gain of all units does affect the performance of a given unit. If the gain remains unchanged however, no change in noise contribution can be effected without an inevitable and predictable change in intermod performance. Raising all levels by 1 dB would mean a system improvement in C/N Ratio of 1 dB, but it would also mean a system increase in intermod contribution of 2 dB.
7.	False	The gain of the amplifiers determines how many amplifiers would be required per mile of plant, and thus does affect the economics of a system.
8.	True	This is certainly true as demonstrated in all trunk/feeder systems, where an end of system performance specification is stated, can be demonstrated, and is maintained over time.
9.	False	Not so. The composite or end of system performance is a combination of the noise and distortion introduced into both sections. It is true that the end of system cannot be better than the performance of either of the sections alone.
10.	B	The conservative transmission design of the trunk plant anticipates little noise contribution from the feeder due to the higher operating signal levels. It anticipates significant intermod contribution from the feeder plant because of those same higher operating levels in the feeder. Thus the trunk may be characterized as a high noise, low intermod system.
11.	True	Since feeder plant does use different amplifiers, usually without AGC for example, and does operate at altogether different signal levels, it should be considered a system in itself, a sub-system as it were. Note that different operating feeder levels does not automatically require different amplifier gain. If outputs in the feeder are higher, so are inputs, and the gain of feeder amplifiers may be the same. or nearly so, as the trunk amplifiers.
12.	True	If the transmission levels are higher in plant, the efficiency of tapping that plant for subscriber service is improved. Since feeder plant usually has many subscriber tap points, raising transmission levels makes feeder plant more cost effective for service tapping. Although this introduces the cost of trunk plant, if there are many taps in an area, and there is a significant ratio between less expensive feeder to more expensive trunk, then the economics of trunk/feeder designs may be attractive. Note that if the demographics of a community or an area do not require many taps in a relatively small area, as in a small town or rural environment for example, the trunk/feeder plant may not be the most economical design at all.
13	C	Since the feeder plant anticipates a high noise contribution from the many trunk amplifiers required in cascade, and a relatively low intermod contribution from the lower output levels at all trunk amplifiers, the feeder plant may be characterized as low noise and high intermod so that a combination of both plants would still be satisfactory.
14.	False	Not so, and an explanation was presented in the answer given to Question 12 for this Chapter.
15.	True	This is exactly what we do in any trunk/feeder design and what we are obliged to do if we incorporate microwave systems or lightwave transmission on optical fibers into coaxial cable systems.

16.	False	This is sometimes called a Rural or Single Cable design, and when the demographics of a service area suggest the practicality of such designs, they are certainly both economically attractive and technically sound.
17.	B	Since coaxial "Super-trunk" is usually intended to feed extensive sections of conventional cable plant, it is conservatively design and not particularly cost effective either. It is not in extensive use anymore with the advent of optical fibers and lightwave transmission, but it could be characterized as low distortion, low noise plant.
18.	True	This is so, and an explanation was presented in the answer given to Question 15 for this Chapter.
19.	False	The "usable spacing" refers to the amount of transmission loss that may be accepted in the system before the signal level falls below the required input to the next amplifier. This loss may be composed of any number or type of passive devices such as couplers or taps, as well as by the cable loss itself. This may also, of course, be cable loss alone, in which case it may translate directly to physical spacing.
20.	False	A coaxial cable system and a lightwave system and a microwave system may all be operated as broadband analog systems.

Chapter 7

1.	True	The ultimate determination of the quality of transmission of any cable system is for there to be no visible impairment of any delivered television signals.
2.	True	Any temperature changes of cable and equipment will make changes in the transmission levels of a system, and thus in the quality of the systems transmission performance. We may, of course, incorporate various forms of correction such as Automatic Gain Control (AGC) to correct for temperature induced changes, but the question was if temperature changes introduced changes in performance. Of course they do.
3.	False	There are other contributing causes of noise in television signals of course. There is some noise in satellite delivered signals for example, or those taken directly "off air." These may, and do, introduce noise into the television pictures that the subscriber receives.
4.	C	In specifying performance of any cable plant, we do not consider the type or nature of the program materials itself. We must, and do, treat all system transmission channels the same regardless of what a channel may be used for.
5.	True	Since each amplifier passed through will make a noise contribution, the system ratio of Carrier-to-Noise (C/N) must degrade or get worse.
6,	False	This is the difference in level of the desired Carrier and the undesired Noise, thus a higher or larger figure would indicate better performance.
7.	True	Certainly. If the intermodulation, as a form of distortion introduced into desired signals were at a lower level, and a more negative number certainly means a lower level, then that is a better system condition. This is an absolute level of interference, not a ratio.
8.	True	Because this is a power addition, the ratio of 1 dB change for a 1 dB change is true.
9.	False	Because this is a voltage addition, the ratio of 1 dB change for 1 dB change is not true. The ratio of change would be 2 dB for 1 dB change in output level.
10.	True	Because this is a power addition, if we combine two equal C/N Ratios, the result would be a decrease of 3 dB.

11.	False	Because this is a voltage addition, if we combine two equal intermod levels, the result would not be an increase of 3 dB, but an increase of 6 dB.
12.	False	If we are to operate any amplifiers at a relatively high input level, then the amplifier C/N Ratio would be very good and might be insignificant. Since the amplifier Noise Figure is a factor in the units C/N Ratio, the Noise Figure may be less significant.
13.	D	The system designer or operator has no control over the quality or age of the subscriber owned television set.
14.	False	As we progress through any cascade of amplifiers, both the C/N Ratio and the intermod will cumulatively and gradually degrade to a point where neither is acceptable or within system specifications.
15.	True	Yes. These specifications, and this level of signal, are not only dictated by the FCC, they reflect the quality of the television pictures that the system must sell as well.
16.	True	At some level, both forms of interference would actually become visible in television pictures to the subscribers.

Chapter 8

1.	False	By definition, a coaxial cable consists of two metallic conductors, separated by a non-conducting or dielectric material, and sharing the same axis.
2.	True	At higher RF frequencies this phenomena becomes more pronounced, and transmission losses through coaxial cables operating in a broadband mode all the way up to 800 mHz and more, emphasize the problem.
3.	True	If the conductor diameter were reduced, or acted as if it were reduced as in this case, then the resistance would be greater and the losses would be higher, wouldn't they.
4.	False	See the explanation for Question 2, this same Chapter.
5.	True	If we maintain the correct ratio between the outer conductor diameter and the inner conductor diameter, we can manufacture a coaxial cable in any size, any outside diameter that is, in any desired impedance.
6.	False	See the explanation for Question 5, this same Chapter.
7.	True	This is so. At 60 Ohms coaxial cable has the best breakdown voltage characteristic and at 30 Ohms, the best power carrying capacity.
8.	False	The characteristic impedance of RG-59 is 75 Ohms.
9.	False	The transmission loss of any coaxial cable, of any size, is not a factor of the characteristic impedance of the cable.
10.	True	Yes, and if we pursued the formulas that apply, we could easily demonstrate this.
11.	True	See the explanation for Question 5, this same Chapter.
12.	True	See the explanation for Question 2, this same Chapter.
13,	True	Yes, and this minimizes the amount of energy that might be reflected from a mismatch of impedances.
14.	C	The level of the reflected energy is in dB, that is, for a return loss of 20 dB at any point of connection, the reflected energy will be 20 dB lower than whatever the input level was there.
15.	False	When reflected energy is confined to only part of the spectrum occupied by a television signal, it is called an "echo." If the reflected energy substantially covers the spectrum occupied by a television signal, it would be called a reflection, and would be apparent as an entire reproduction of the television signal, horizontally displaced somewhat on the TV set screen.

16.	B	If a reflection is visible on a screen, it could occur at any frequency or might appear on any, or several, channels.
17.	True	Periodic irregularities are sometimes introduced in coaxial cables as they are manufactured, perhaps by passing all cable over a pulley with a mechanical irregularity in it. Even small irregularities, if periodic in spacing, can cause severe distortions in cable losses at some frequencies, and when these faults are mechanical in the cable itself, they are called "structural return loss."

Chapter 9

1.	False	The transmission losses of coaxial cables increase as temperature rises, and decrease as temperature falls.
2.	True	If we are to control level variations due to temperature changes, we obviously cannot do this manually, and some form of Automatic Regulation is necessary.
3.	True	Of course.
4.	False	In the early days of Cable Television, we usually did add unmodulated carriers to systems for regulation purposes, but we can regulate systems by sensing modulated carriers and we do now. We simply use one of the television carriers that the system is normally carrying for subscriber use, thus reducing the system RF load.
5.	False	We can and this is exactly what we do in AGC and ASC amplifiers.
6.	False	We no longer add separate Pilot Carriers to systems. See the explanation for Question 4, this Chapter.
7.	True	AGC does make "flat" corrections, that is, all signals are raised or lowered by the same amount regardless of their frequency.
8.	True	In order to give more level control to frequencies that might vary substantially in level, as in the case of broader band transmission systems, two adjustments might be made, each covering a portion of the band, and each reacting to the transmission level of a different control carrier. Such control is called Automatic Slope Control.
9.	True	Yes, if we are to adjust more than one portion of spectrum, then we must sense the level of more than one control carrier.
10.	False	The normal or average ambient temperature is taken to be +68 degrees Fahrenheit, not +48 as the question states.
11.	False	We set the adjustment range for AGC action to correct for both higher and lower temperatures, thus when we have set it for +3 and -3 correction, we should assume the ambient temperature, with the normal signal input level, was at +68 degrees Fahrenheit, not 90 degrees as the question states.
12.	True	If the AGC were adjusted for middle correction, that is +3 and -3 at some temperature extreme such as +90 degrees Fahrenheit, when the temperature did return to a normal - 68 degrees, it would no longer have a +3 and -3 capability since it would have had to switch in some attenuation to compensate for the temperature change.
13.	False	Without proper AGC action, almost all systems of any significant cable length, would experience such temperature changes, and consequently such changes in signal levels, as to actually go out of performance specifications.
14.	A	There is no reason for improper AGC action to cause any periodic failures of operating power.

15. False There is no reason to expect system RF transmission continuity to be affected by improper AGC action. Signals may be out of spec and unusable, but continuity would prevail.
16. True A loss of AGC action probably would do this.
17. True It surely can have that effect.
18. True Yes, even with the correct system design, proper selection of AGC equipment, and proper functioning of that equipment, improper adjustment can offset all of this.

Chapter 10

1. False If the input signals to the two amplifiers were low, as we would expect on a hot day, then the C/N Ratio of these two amplifiers would be poorer, not better as the question stated. Given lower input signal levels, the output levels of these two units would also be lower, and consequently the intermod performance of these two amplifiers would be better.
2. False As temperatures go up and down, so do input and output levels on non-regulating amplifiers, and thus the intermod performance of the unit would change.
3. True If noise contributions increased, this would be due to lower signal levels, and there would be a corresponding decrease in intermod performance.
4. True These are the factors that an engineer would use to determine the spacing and location of Automatic Regulation in a system.
5. True True, because correction is normally applied for two sections of the system bandwidth, and particularly so in a system offering substantial bandwidth for transmission use.
6. False Since all or most of the cable is actually placed underground, and since temperature changes are somewhat limited by the cable burial, underground systems require less, not more, Automatic Regulation.
7. False The insertion of Automatic Regulation in a system, and the spacing of such Regulation, is determined by the ambient temperature changes anticipated and the lengths of coaxial cable to be exposed, and does not consider the amplifier gain as a factor. Of course higher amplifier gain might mean longer lengths of cable to be subjected to the temperature changes.
8. A If more frequent Regulation is installed, then the normal correction for each regulating unit would be less. If excessive correction is provided in each unit, and the system lost regulating carrier, then the system could switch out too much attenuation, and signal levels might put the system out of specifications.
9. False There may be a relationship between customer complaints and proper AGC action, and correct Automatic Regulation can definitely reduce long term operating costs.
10. True Line extender amplifiers do not usually include any Automatic Regulation because the cable lengths are distinctly limited by the frequency of subscriber taps and by the limitation on feeder length itself.
11. True There may not be sufficient coaxial cable lengths to require regulation, and this may be further assisted by the limitation of amplifiers in cascade.
12. True Given a loss of regulating carrier, most Regulating units do switch out all remaining attenuation, and this can result in excessively high system signal levels.
13. False If a regulating unit were improperly adjusted, under some temperature conditions the system signal levels would change, but this may not automatically introduce a complete interruption of transmission continuity, though it may make end of system performance fall out of specifications.

14. False Most AGC, does not self adjust to a mid-range of attenuation. These are not "smart" units, they normally open up completely and remove all remaining attenuation.
15. True Most modern systems do use more than one regulating carrier and do provide some level of Automatic Slope Adjustment.
16. True The most common incorrect adjustment on cable systems is Automatic Regulation, and any such maladjustment can, and often does, affect transmission quality through the system.

Chapter 11

1. True Since these frequency "ripples" are random, and not pronounced, we usually do not make any effort to frequency equalize them.
2. True Since the frequency response distortion due to the cable itself is more pronounced, and is somewhat predictable in nature, we do try to equalize this frequency response in all systems.
3. True This is exactly what equalizers attempt to do in a system.
4. False Each amplifier is intended to offset the losses of the cable section immediately preceding it, and each equalizer is intended to offset any signal "tilt" that the preceding cable section may have introduced, or some of it. Equalizers actually are used to provide all signals at the same level at the input to the gain module itself.
5. True Since the Noise Figure of a unit is the same at all frequencies passed, to equally protect the C/N Ratio of all signals, we need to hit the gain module input with all signals at the same level, or nearly so.
6. False The equalizer is directly associated with the preceding section of cable, and not with the amplifier gain module at all. We change out the gain module if it fails, but we retain the same cable equalizer unless the trouble is in that unit itself.
7. C Equalizers do not introduce any gain at all, and they do introduce different losses at different frequencies.
8. True This is so, and if the minor but periodically spaced defects are in the cable itself, it is called "structural return loss."
9. True If a cable introduces sharp, limited transmission losses and such is limited to only portions of the spectrum, such transmission discrepancies are called "suck-outs."
10. True This is exactly why we "tilt" the amplifiers output. If we were only concerned with equalizing signal inputs at the next amplifier, we could rely on equalizers at that location alone. This accounts for the intermediate use of in-line equalizers in some systems also, particularly systems with extensive transmission bandwidth. Of course we do achieve some improvement in amplifier intermod by "tilting" before the last amplifier stage, also.
11. True We usually locate cable equalizers within amplifier housings, and since most amplifiers are preceded by a significant length of cable, those equalizers are selected accordingly, but electrically, the equalizer is not directly associated with the amplifier itself.
12. True Of course, they are coaxial cables and evidence all characteristics of such.
13. False Not true. Since the equalizer is associated with the preceding cable section alone, there is no reason to change it out simply because the amplifier module may have failed.
14. False No. The amplifier Noise Figure is directly associated with the amplifier input alone.
15. True Of course. Since the system bandwidth is extensive, sensing and correction is required at different points in the system bandwidth.

16.	True	The objective of all cable systems is to hit all sets fed with the same signal level, and to have all signal levels the same there.

Chapter 12

1.	True	Of course. Design or layout of a system must meet all these criteria.
2.	True	Same as answer to Question 1, same Chapter.
3.	False	Same as answer to Question 1, same Chapter.
4.	False	No. There is no Noise Figure for a tap.
5.	True	The actual location of any such equalizers will depend on the cumulative transmission calculations and the signal "tilt" so introduced, thus this is a function of system design or layout.
6.	False	No. Same answer as Question 5, same Chapter. Besides, the pads or attenuators are associated with the amplifier input, not the output.
7.	False	As well as how many television sets may be fed at that premises and the length of the drop itself, the size and loss of the service drop cable used must ne considered.
8.	False	Same answer as Question 5, same Chapter.
9.	True	Of course. In this respect, the design of Cable Television systems differs from the design of Local Telephone networks where transmission losses for each point of service need not be calculated at all.
10.	False	They not only can, they are. The result is no change in signal levels further down the system, but a significantly lower signal level will be delivered to the drop cable itself, due to the high isolation loss of the tap.
11.	D	Same answer as Question 10, same Chapter.
12.	True	Yes, but system specifications must be independently decided and put into the computer program.
13.	C	A number of high value pads at amplifier inputs could indicate an inefficient system design.
14.	True	This is the specific function of back-feed cables.
15.	True	The tap insertion losses would be lower, and thus the tapping efficiency may be improved.
16.	False	The feeder signal levels are significantly higher than the trunk levels in a trunk/feeder system. Of course the performance of each feeder amplifier reflects this as well.
17.	False	Not necessarily. The feeder amplifiers may have the same, or nearly the same gain. They are just operated with higher input levels and thus with higher output levels as well.
18.	True	If we are to operate the feeder plant at different levels, we need a separate gain module to allow us to set the feeder levels without compromising or changing the trunk levels. The bridger module does just this.
19.	False	No. Since trunk plant usually uses larger size and higher cost cable, and trunk amplifiers include some level of Automatic Regulation, trunk plant usually costs more per unit than feeder plant.
20.	False	No. There usually is trunk plant to arterially feed signals throughout the service area and much more feeder plant to provide access to the system to all subscribers served.

Chapter 13

1.	True	This is the definition of a splitter.
2.	True	Depending on its actual design, a three way splitter may have equal outputs on all three ports, or it may have two lower level outputs and one higher level output.
3.	True	The value in dB reflects the transmission loss to the tap port and the insertion loss is a function of the coupler value itself.
4.	True	That is why they are provided in a variety of values.
5.	True	Yes.
6.	B & C	Tap values are, in the layout or design phase of any system, selected for each location to supply a required level of signal to feed that subscriber drop. Of course such selection will depend on the signal level available at that point in the system.
7.	True	This is so, and reflects the unique geography of any system. It may have cul-de-sacs, or portions may be on a river or lake front, and in some cases different cable routings are possible.
8.	D	If we find a number of cable ends that are simply dissipating excess signal in terminating resistors, we might suspect the design of the system to be less efficient.
9.	B	Yes, we might suspect Automatic Regulating units to be improperly spaced, improperly adjusted, or inoperative.
10.	False	Not always. A subscriber located off by itself or with few neighbors may require system extension to serve only those few stations. In such cases, this cannot be entirely overcome by better system design.
11.	True	Although changing both the input and output levels of any amplifier, or any cascade of amplifiers, would change the transmission performance, unless we actually change the gain of a cascade of amplifiers, we would not change the spacing of those units, and thus would not alter the economics at all.
12.	False	If we can, with no compromise of transmission performance, change the ratio of expensive trunk plant to less expensive feeder plant, we certainly would change the cost effectiveness of that system.
13.	True	The end result might be a more efficient tapping of the system for service, and an increase in overall reliability as well. If done thoughtfully, this need not compromise transmission performance of the resultant hybrid system at all.
14.	True	No question. Service calls and system maintenance would be significantly and beneficially affected.
15.	True	This is certainly true. There is no valid reason to expect any impact at all on power outages.

Chapter 14

1.	True	This would be a generally accepted definition of an urban system itself.
2.	True	Because there are so many taps distributed throughout an urban system, the efficiency of system tapping for service does become a significant factor in the approaches to urban system designs.
3.	False	There are no system designs that are universally technically optimum for all applications, nor are they universally cost effective in all instances.

4.	True	There is no National or International network of Cable Television services, although specific programming may be Nationally distributed and displayed. For all practical purposes, Cable Television service can be considered Local and restricted in nature.
5.	False	Not true. By incorporating optical fibers into distribution systems, for example, we might limit the extent of coaxial plant and thus the cascade of coaxial amplifiers, and this might raise acceptable transmission levels and beneficially affect the efficiency of dense system tapping for service.
6.	True	Of course.
7.	False	Not so. Trunk amplifiers, since there are many such units in cascade, are operated at conservatively lower levels. Feeder amplifiers, by limiting the number in cascade, can be operated at higher, more distortion producing levels to improve tapping efficiency.
8.	False	If we operate at too low an input level, the C/N Ratio may be unacceptable. If we operate at too high an output level, the intermod distortion contribution may be unacceptable.
9.	False	Not so. See answer to Question 7, this Chapter.
10.	False	No. Feeder plant is operated at substantially higher levels, introducing a second transmission level into the plant, for a different reason, to improve tapping efficiency.
11.	False	Not so, because trunk plant usually uses larger size, lower loss, higher cost cable to restrict the number of amplifiers cascaded, and because trunk plant normally incorporates some level of Automatic Regulation, trunk plant is usually less cost effective.
12.	False	No. Since they transition signal levels to a higher level for application to the feeder plant, they are operating at higher output level and are considered part of the feeder transmission system.
13.	A	Since operating output levels on trunk amplifiers are usually conservatively low, they have characteristically lower intermod contributions, not higher.
14.	True	Of course. See answer to Question 7, same Chapter.
15.	C	Because all feeder amplifiers do operate at higher output signal levels, they do contribute substantially to system intermod.
16.	True	Since both types of plant, operating at different signal levels, have different noise and intermod contributions, performance of each must be calculated separately and overall transmission performance must incorporate both performances.
17.	True	Of course.
18.	False	No. We need only parallel or place two cables along the trunk route itself, not throughout the system.
19.	True	By arbitrarily limiting the length of feeder plant, and thus the cascade of feeder amplifiers, we can tolerate higher output levels and higher intermod contributions from feeder amplifiers..
20.	True	Of course.

Chapter 15

1.	True	This might be called the classic definition of a rural application.
2.	False	Since the service area may be extensive, and the tapping is infrequent, the paralleling of trunk and feeder cable required in a trunk/feeder system is not very cost effective in rural applications.

3.	True	No question that the transmission performance and service quality are equally obligatory in both rural or urban applications. The system engineer is in no way relieved of the necessity for quality in either case.
4.	True	The result in rural systems is one set of transmission levels rather than different signal levels in different sections of the system.
5.	True	Since only one set of transmission levels is involved, we do not need transitional bridger units, and we do not have separate trunk and feeder amplifiers either. Generally the only two types of amplifiers would be those with, and those without, Automatic Regulation.
6.	A	Only one cable for both transmission throughout the service area and for service tapping are used in a rural design.
7.	False	No. If a rural system, employing trunk transmission levels alone, were constructed, the most distant stations would be at, or nearly at, the C/N Ratio specification and would not be at, or nearly at, the intermod specification. The system so constructed would not be as cost effective either.
8.	False	No. If the system did employ feeder signal levels. the end of system would be quickly out of intermod specifications and would not be at C/N Ratio specifications. The system would also not be as long, or as cost effective either.
9.	False	Not higher cost but lower cost, since they need not install any paralleling cable and use only two types of amplifiers.
10.	A & D	Rural systems use amplifiers that do have more gain than conventional trunk units, and there is no special restriction on system bandwidth either, other than those of higher losses and more gain that apply equally to trunk/feeder systems.
11.	C	The operating signal levels in rural plant fall between the low levels of trunk plant and high levels of feeder plant. They are not the same as either trunk or feeder signal levels.
12.	False	There are no special restrictions on rural system bandwidth other than the same restrictions that apply to trunk/feeder systems, and these are higher losses and more gain required to offset them.
13.	A & D	Correct. See answer to Question 11, same Chapter.
14.	True	Since there are only one set of levels, there is only one set of computations, and transmission performance is simpler to calculate in rural systems.
15.	True	Of course.
16.	True	When the service area and the cascade of coaxial amplifiers is limited, the single cable, or rural design, makes a great deal of sense for the coaxial portions of hybrid systems, and we may well operate such plant at somewhat higher levels than conventional feeder plant, as well.

Chapter 16

1.	True	Just one example of that is when coaxial cables using RF transmissions and frequency division is employed in Local Area Nets (LAN's) for closed circuit data networks.
2.	True	Perhaps replaced by optical fiber transmission systems, the use of coaxial Super-Trunk is still a technically valid application of coaxial cable, and some may still be in use somewhere.
3.	True	Yes, Super-Trunk designs were extremely conservative and did make minimal contributions of both noise and intermod.

4.	False	No, Super-Trunk usually used larger size, higher cost cables, and was not, nor was it intended to be, particularly cost effective. Reviewing it does help us understand RF transmissions on coaxial cables a little better, even if this particular technique has become less frequently employed or encountered.
5.	False	Not so. In order to minimize intermod contributions, this plant did not, usually, use either higher gain or higher transmission levels.
6.	True	These cables usually parallel some of the conventional coaxial Cable Television plant, and are intended for other use than for Cable Television service alone.
7.	True	Since this plant is intended for other uses than conventional Cable Television service, it often employs a different division of usable bandwidth, which may take the form of Mid-Split design rather than the conventional Cable Television Sub-Split concept.
8.	False	No. Providing that at any end or extremity of any trunk/feeder system, some contribution of both noise and intermod is still acceptable and still meets all system specs, any plant could be extended as a single cable or rural type design for some limited distance, and operating signal levels for that section of any system could be determined accordingly. This might allow limited extensions of any system to feed trailer camps or condominiums normally beyond technical extensions of that system.
9.	True	Yes.
10.	True	The overall performance is certainly a combination of all contributions, and all sources must be individually calculated and some form of consolidation is necessary.
11.	True	The best example of this is a combination of optical fibers and coaxial cables. The fibers are operated on an analog, broadband basis using frequency division to separate the different signals and to modulate the lightwave carrier. The coaxial cable portion of the system is also analog and broadband. At the point of interface or interconnection, we need not process individual signals at all. All that is required is to detect the lightwave carrier and the result is to reestablish the original carriers on frequency as a group, fully compatible with the coaxial plant and its bandwidth. No individual signal processing is required.
12.	True	Yes, the separation of individual desired signals is on a frequency basis, and desired signals are individually tune in.
13.	False	Time division multiplexing is not used in most Cable Television systems today. The common technique is frequency division.
14.	False	Not so. We do specify performance between the cable system interfaces for all the reasons given, but the cable plant is not the only contributor of noise and intermod to the subscribers signals.

Chapter 17

1.	True	Not only are all systems constructed with this capability, they are obliged to have this capability inherent in their design, even if they are not so equipped initially.
2.	True	Yes.
3.	True	Most plant used for Cable Television service does use a Sub-Split philosophy and this does entail a frequency separation below Chan. 2.
4.	True	Yes.

5.	B	Mid-Split is considered to provide 5 to 108 mHz spectrum in one direction and 174 on up in mHz in the other direction.
6.	True	Since all amplifiers outputs are collected or sum up at the Head End, their individual noise contribution must be considered.
7.	True	Cumulative or total noise and intermod contributions on a loop back or turn around basis must consider the contributions from each individual direction of transmission.
8.	False	No. Only those return amplifiers that are passed through contribute to the return transmission intermod.
9.	True	Yes. All return amplifiers contribute noise to the return transmissions whether they are passed through or not. See answer to Question 6, same Chapter.
10.	D	Transmission from the Head End out to all stations served is often called Downstream Transmission, and from the stations back to the Head End, Upstream.
11.	True	At each appearance, including system amplifiers and subscriber stations, if separate spectrum is to be employed for different directions of transmission, then some means to separate these two spectrums is required, and one practical method is filters.
12.	False	No. It is practical to utilize the existing amplifier housings and power supplies, and since the Downstream amplifiers are already located, the Upstream amplifiers are obliged to conform to these locations, even though they may not always be optimum. This sometimes accounts for excessive pads in the upstream path, which is not always efficient transmission.
13.	False	Yes, we may find this widespread. See answer to Question 12, same Chapter.
14.	A&C	It certainly is interactive if it allows return transmissions, and it is interrogative on a time shared basis if it only allows one station to transmit back at a time. It surely is not full time or full talk return transmission, is it?
15.	True	Of course.

Chapter 18

1.	True	This is so in almost all coaxial cable plant.
2.	False	Not so. Taps, for example, do not pass operating power to service drops, and some splitters or couplers may not pass power to some cable leads where no operating power is needed.
3.	True	There is a separate, independent transmission path for 60 Hertz through these devices.
4.	True	This is the method used in most equipment. The filters may consist of choke coils plus capacitors.
5.	False	Not so. Most systems do not supply operating power to service drops.
6.	B	Operating power in most cable plant is 60 Hertz at 60 Volts.
7.	True	These units normally step the operating AC power down to 60 Volts from the more common 117 Volts that commercial power supplies. 60 Volts AC is usually coupled onto the coaxial cable itself to operate a portion of a system, and additional locations are equipped as required.
8.	False	No. Amplifier power supplies generally accept, rectify to DC, and regulate operating power for use in the gain modules or what have you.
9.	True	Yes.
10.	False	Not so. Depending on the current drawn and the resistance of each cable section, the operating power voltage will experience some Voltage drop. At some point it is too low to use and properly regulate, and another system power section must be established.

11.	C	The correct formula is E (Voltage) = I (current) times R (Resistance.) The resistance is loop resistance of any specific coaxial cable including center conductor and outer conductor resistance.
12.	False	Not true. If the AC input Voltage to any amplifier is too low, the unit would fall out of regulation and its DC output Voltage may be too low for normal amplifier operation.
13.	True	Of course, since an amplifier or several amplifiers would not operate at all and would interrupt service.
14.	True	During system design, calculations of operating voltage must be made, manually or by computer program, to insure correct and acceptable Voltage to all stations supplied.
15.	True	Since a fully loaded station may be added at any time, and would draw more current, we must assume the worst case load for all stations initially, or line power locations may not, subsequently, be adequate.
16.	True	Yes, or power voltage for the system extension may be too low for proper operation.
17.	False	Splitters and directional couplers are initially capable of passing operating power but in some cases, this capability may be disabled in specific units.
18.	True	Yes.

Chapter 19

1.	True	This is the generally accepted definition of coaxial cable.
2.	True	Yes.
3.	False	Using air as the dielectric, a coaxial cable will evidence less transmission loss, not more.
4.	False	Air entraining foam dielectric cables will evidence more loss, not less loss, than a cable using air as the dielectric.
5.	True	Of Course.
6.	True	Yes.
7.	True	We do, usually, use larger size, lower loss cable for trunk plant, and thus cable costs are generally higher in trunk than in feeder.
8.	False	The universal characteristic impedance of all coaxial cables used in Cable Television systems is 75 Ohms, not 60.
9.	True	Yes.
10.	False	No. Self-support cable does not lend itself well to lashing two cables on a single supporting wire or cable, and trunk plant usually requires the placement of two, paralleling cables. Thus self-support cable is seldom if ever used in trunk plant.
11.	True	It is required in order to calculate the Voltage drop through any section of the cable plant.
12.	True	All this information is available from the cable specifications.
13.	False	Not so. Air dielectric material evidences the least loss, and solid dielectric material the most.
14.	True	This is so. The layout people are not empowered, generally, to select any particular cable. They are required to employ a cable that has been determined to be technically and economically best by the system engineer.
15.	True	Yes.
16.	False	Service drop cables, like all cables employed in Cable Television systems, have a 75 Ohm characteristic impedance, not 50 Ohms as stated.

17.	False	By marking such drops, and perhaps selecting a different tap value or a different loss service drop cable, unusual drop applications can be relieved during the layout process.
18.	True	It most certainly does.

Chapter 20

1.	True	Yes.
2.	False	On satellite delivered signals, the modulation employed is FM for video information. In commercial broadcasting, this information is AM modulated.
3.	False	Due to the FM modulation used for satellite delivery, and the AM modulation used on the cable system for presentation to subscribers TV receivers, we cannot simply employ hetrodyne processors and must demodulate, and remodulate, each such channel. The demodulation is performed by the satellite receiver itself, and we must use a separate RF modulator for each channel.
4.	A	A hetrodyne processor does not perform demodulation and remodulation, it only converts the incoming AM modulated signal to an IF frequency, and then converts that IF frequency to an AM modulated RF output.
5.	False	Not so. To insure maximum transmission performance, and to take advantage of FM improvement, these signals are FM modulated.
6.	True	Yes. Since, with satellites, the modulation is FM, and we require AM modulation on the cable system itself, we must change the modulation, and that requires demodulation to video, and remodulation as an RF carrier with AM modulation.
7.	True	These receivers do demodulate and their output is video and audio.
8.	D	The equipments required are satellite receivers to demodulate the incoming signals to video and audio so that a modulator may be employed to AM modulate this video on an RF carrier.
9.	True	If the cable signals are to be directly compatible with the subscriber owned TV receivers, we must carry AM modulated video and FM modulated audio for all RF carriers on the cable system.
10.	True	This is so, and they are referred to as geostationary to reflect their apparently fixed relationship to any given location on the earths surface.
11.	True	Yes.
12.	False	A transponder for each channel delivered by the satellite is supplied.
13.	True	This is so. Additional isolation, and thus channels may be spaced closer together, can be provided by using antenna cross-polarization in this manner.
14.	False	Because of the very low received signal levels, and because waveguide or coaxial cable losses are high at these frequencies, low noise amplifiers, and low noise converters also, are usually employed at earth satellite receiving stations.
15.	True	This is possible.
16.	True	This is also possible.
17.	False	Almost all Cable Television systems today receive at least some of their programming via satellite delivery.
18.	True	Almost anywhere in the United States, and many locations throughout the world as well.

Chapter 21

1.	True	Yes.
2.	True	This is so in some systems.
3.	True	Since satellite modulation is FM, and the cable system requires AM, demod and remod is necessary, but we use a satellite receiver for demod and then a conventional RF modulator.
4.	True	This is the generally accepted definition of the term.
5.	True	Since a heterodyne processor does not incorporate any modulation process at all, there cannot be any recommended depth or index of modulation.
6.	False	Since a remodulation is necessary, heterodyne processors are not used.
7.	True	Demodulators take a modulated RF signal input and demodulate it to recover the audio and video information. They do not accept audio and video as inputs for processing.
8.	True	Off-air RF signals may be processed with a heterodyne processor.
9.	True	All signals must be combined somewhere to provide one single, broadband cable feed.
10.	True	Preamplifiers usually have a better Noise Figure, and by installing them at the antennas, before the down lead loss is experienced, they do improve the C/N Ratio of the signal being handled.
11.	False	In early days, when systems did not carry so many signals, Pilot Tones were separate carriers. These additional carriers did load a system somewhat, and present technology uses a conventional signal RF carrier for Regulating purposes.
12.	True	For example, antenna down leads for off-air signals may be placed on one side of an equipment rack, with the much higher level output signals placed along the other side of the rack. This is good practice and does provide some additional isolation.
13.	True	Yes, but to improve electrical isolation, these units are usually installed so as to provide the coupler higher isolation loss between adjacent units.
14.	True	If this spectrum is to be used separately for various services, then this spectrum must be isolated at the system Head End, just as it must be isolated at all amplifiers locations as well.
15.	False	Satellite signals are FM modulated and the cable system, and the subscriber's TV sets, requires AM video modulation, thus satellite signals must be demodulated and remodulated in most cases.
16.	True	This system test point is employed to insert sweep test and other signals as necessary, and is often a permanent part of the Head End itself.
17.	False	Although the Head End may be, and often is, used for a line power supply location, such power supplies do not usually output 60 Hertz at 90 Volts as stated. They usually put out 60 Hertz at 60 Volts, just as all system line power supplies do.
18.	True	The isolation of subscriber stations into small groups in this fashion will improve the reliability of the service also, that is, a single amplifier failure will not necessarily affect service to thousands of subscribers.
19.	True	These log sheets should include a space for the date, the time, the ambient temperature, and for accountability, the technicians initials for every entry made.
20.	True	Of course not.

Chapter 22

1.	True	This distribution of sophistication, when applied, may be more a business or economic judgement than an engineering judgement.
2.	True	Microwave systems are often used for signal transportation in the Cable Television industry.
3.	True	Some transportation systems are necessitated by geographical features also, such as rivers or bays, for example.
4.	True	They require unobstructed line of sight and some small clearance as well.
5.	False	These units do require audio and video feeds so that this intelligence can be modulated onto the microwave carrier itself.
6.	True	The process is heterodyning all the signals against a local oscillator and no true modulation is required. At receiving sites, the same heterodyning against a local oscillator restores all input signals with the same relationship, and on the same frequencies, as they originally had.
7.	True	They certainly do.
8.	True	The process whereby several pulse streams are integrated into a single, high bit rate stream, is called multiplexing. In Telephone systems, where the requirement is for many individual circuits between two Offices or points, this is mainly how lightwaves are used.
9.	True	We can, of course, choose to operate lightwave systems as analog, broadband installations just as we do with coaxial cables, and we can also employ frequency division to separate signals, as in conventional cable systems.
10.	True	Yes, when lightwave systems are operated as broadband, analog systems, they are fully and practically compatible with coaxial cable plant. This is the way optical fibers have been effectively used by the Cable Television industry.
11.	True	AML microwave systems are most cost effective, carrying many channels and carrying those channels to several receiving locations as well. This is the way that they have been largely employed by the Cable industry, and this is why AML systems are widespread as well.
12.	True	In appearance and in practical application, lightwave receivers are incorporated into hybrid optical fiber/coaxial cable systems easily and inexpensively.
13.	True	Transmission wise, they act much like the coaxial cable sections. These are analog, broadband transmission links that interface with the coaxial cable nicely. This is how they have been used in most Cable Television systems.
14.	True	Digital transmission is not common in the Cable Television industry today. Of course a single television carrier can be digitally modulated with video and then that carrier may be mixed in with any number of other carriers that are frequency division separated but used AM video modulation instead, thus some signals may be digitally modulated, but not digitally multiplexed, in cable systems.
15.	True	There is a real difference in digitalizing a single signal, and in digitally modulating an RF carrier or a lightwave carrier with that signal, and multiplexing any number of digital signals into one pulse stream.
16.	True	See answers to Questions 14 and 15, same Chapter.
17.	True	Such decisions might reflect local geography such as rivers or bays, as well, and may well be more business judgements than technical ones.
18.	True	Because they use spectrum in the public domain, they must be licensed.

19.	True	Because these are physical facilities that are closed in nature, that is, they are not freely available to the general public, such facilities require no Federal licenses.
20.	True	Yes of course.

Chapter 23

1.	False	Light can be thought of as a system of waves or a system of particles. Sometimes it acts as waves, and sometimes as particles. The nature of the interaction with different matter determines if light acts as waves or particles.
2.	True	A photon is a massless bundle of electromagnetic energy. Light is kinetic energy, and kinetic energy is associated with movement. The photon, the unit of light energy, cannot be captured and put on a scale, for instance. When a photon is "caught," such as when light is absorbed by a material, the photon ceases to exist as such.
3.	True	Like sound waves or radio waves, light is electromagnetic energy and travels in a wavefront.
4.	False	The wavelength of an alternating wave is the distance it travels in one full cycle.
5.	False	Wavelength may be stated in units of length measurement of course, providing that we know the velocity of propagation, and this will be different for media.
6.	False	Lightwaves of different frequency, travel at different speeds, even when travelling in the same medium.
7.	False	As frequency gets higher, the wavelength gets shorter. Thus 800 nanometers would be the wavelength of a lower frequency than one whose wavelength was 1300 nanometers.
8.	True	For thousandths, we use micron or micrometer to denote a millionth (10^{-6}) of a meter, and for billionths of a meter (10^{-9}) we use the term nanometer, thus 1 nanometer is one billionth of a meter.
9.	False	All lightwaves used in telecommunications systems today are not all visible frequencies.
10.	True	For example, when light impinges on your skin, it is converted into heat, and your skin actually feels warm.
11.	True	This is true of some materials, and is called the photoelectric effect.
12.	True	Within the visible light spectrum, different frequencies are associated with different colors.
13.	False	It is the same angle as the angle of reflection.
14.	False	In any medium, the primary causes of light attenuation are scattering and absorption.
15.	False	The term originated to denote higher frequencies, where the wavelengths are actually shorter, thus the term "shortwave."
16.	True	"White" light does contain all the visible spectrum lightwave frequencies. If all the visible frequencies are present, the color is white, and if none of the visible spectrum lightwave frequencies are present, the color is black.
17.	True	Light is kinetic energy, and kinetic energy is associated with motion.
18.	True	Since light is electromagnetic alternating waves, it can be identified within the general electromagnetic spectrum.
19.	True	In a vacuum, all electromagnetic waves, including light, travel at a speed of 186,280 miles per second.

Chapter 24

1.	False	The Law of Inverse Squares applies, and the level of illumination is not constant across the surface if the distance from the source of light changes.
2.	False	Color exists only as an observed sensory perception and is not a physical characteristic of any substance or material.
3.	False	Monochromatic is consisting or having one color or hue, which means having only one lightwave frequency present.
4.	True	Incandescence is the emission of visible light by a hot body.
5.	False	Light scattering does not occur in a vacuum.
6.	False	The condition stated in the question is scattering, not absorption.
7.	False	The primary causes of light attenuation are scattering and absorption, not incandescence and fluorescence.
8.	True	Light is electromagnetic energy, and does travel in a wavefront, like other electromagnetic waves.
9.	True	Radiant energy is measured in units of power, and the unit of power is the Watt.
10.	True	Some forms of light power meters do count the number of photons that strike a photosensitive material.
11.	False	A ratio is the relation in degree or number between two things, but they are two similar things, not dissimilar as the question states.
12.	True	The decibel is a commonly used term for the ratio between two levels of lightwave energy.
13.	False	Decibel-milliwatts denotes a specific level of power, not a ratio between two levels. The correct term here would be decibel.
14.	True	The shorter wavelengths are more susceptible to scattering, and blue is a shorter wavelength.
15.	True	Yes, of course.
16.	False	Light can be either digitally or analog modulated with intelligence.
17.	True	Both forms of light can be measured and the unit of measure is the Watt.
18.	True	The process described is called absorption.

Chapter 25

1.	True	Of course.
2.	True	In addition to the mechanical and optical problems of fiber splicing, the numerical aperture of both fibers is a factor.
3.	True	Digital modulation is a signal expressed by a discrete state that may be the presence or absence of a voltage, the level of amplitude of a voltage, or the duration of the presence of a voltage. Turning the light intensity up or down is equivalent to two states of the amplitude of a voltage.
4.	False	Modal dispersion is not most prevalent in single-mode fibers.
5.	True	This is a Law of Physics that applies to light.
6.	True	A distinct transition is the definition of a step index fiber.
7.	True	This is the definition of numerical aperture.
8.	False	Graded index fiber depends on refraction, not reflection as the question states.
9.	False	Light does not propagate reflectively through a single mode fiber.

10.	False	In a single mode fiber acting as a waveguide, some of the light energy actually propagates through some of the fiber cladding material and this active portion of the fiber, that is, the portion through which light actually is propagating, is called the "mode field diameter." This is not the same as the core material diameter, it is larger.
11.	True	The reflections are a function of the wavelength, and because light wavelengths are so small, the fiber is required to be of small diameter to insure correct internal reflections.
12.	True	Smaller numerical apertures help control internal reflections of course, but since the resultant cone of acceptance is smaller also, they do make it more difficult to couple light energy into fibers.
13.	True	Since they have little or no modal dispersion, single mode fibers do present greater bandwidth for use than graded index fibers.
14.	False	Fibers offering greater bandwidth for use do support higher data transmission rates.
15.	True	The definition of a step index fiber is that there is a definite transition between fiber core and cladding, and consequently between the refractive indexes of each.
16.	True	This is true of graded index fibers, but is not true of single mode fibers.
17.	True	A single mode fiber satisfies the definition of a step index structure in that there is a distinct transition in the refractive indexes of the core and the cladding materials.
18.	True	In single mode fibers a significant amount of light energy actually does propagate through the cladding material. The active cross-section of the fiber, of both core and cladding in this case, is called the mode field diameter.

Chapter 26

1.	True	Fibers do function as light energy waveguides, as a matter of fact, they are sometimes referred to as light guides.
2.	False	Light scattering in optical fibers is largely due to the absorption of photons in the molecules of the glass itself, which re-emits the light energy. Reflection within the fiber has nothing at all to do with it.
3.	True	Scattering loss is also a function of wavelength, and we will always experience lower fiber attenuation at longer wavelengths.
4.	True	It is the scattering phenomenon that always produces less fiber loss at longer wavelengths.
5.	True	Peaks in fiber losses across the spectrum offered are due to the foreign elements or impurities within the glass of that particular fiber.
6.	False	The terms "first" and "second" windows refer to those sections of spectrum which show the lowest loss, not the greatest as stated in the question.
7.	False	Irregularities or mechanical problems at the fiber cladding and core interfaces will disturb the propagation of light through the fiber, and will have an effect on fiber attenuation.
8.	True	Loss in optical fibers is defined as a loss or attenuation of light energy as it passes through the optical fiber.
9.	True	Fiber loss is generally stated in terms of unit length, and the term dB/km refers to the loss of one kilometer of fiber.
10.	False	Transmission levels in optical systems may be referred to as discrete power levels in mW or as referenced power ratios in dBm. The term dBmV denotes decibels referenced to a millivolt, and these levels are generally not encountered or appropriate in lightwave systems.

11. True Pulse broadening in digital systems does alter the time periods of pulse presence or absence, and does cause intersymbol interference.

12. True The material from which the glass itself is fabricated and from which the fiber is drawn does contribute to the attenuation curve of a fiber.

13. True Different materials may be added in making glass from which fibers are drawn, and adding different amounts or different materials is called "doping."

14. False Light absorption is a function of the impurities in the glass material itself. This is one reason for doping, or adding other materials to the glass during fabrication.

15. True The overall link loss can be established by simply multiplying the fiber loss per kilometer by the link length in kilometers.

16. True The lightwave input to the receiver is determined by subtracting all link losses including fiber losses from the transmitter output in dBm. The result in dBm is the receiver input level.

17. False In an analog system, link performance is not called out to be BER. Compatible terms are used such as C/N Ratio, Composite Triple Beat, etc., so as to facilitate combining this performance with that of coaxial cable extensions in hybrid systems.

18. False Not only is there a correlation, it is possible to make all link calculations on Rise Time or bandwidth if desired. In analog systems as used in Cable Television, bandwidth is most relevant and most commonly employed and specified.

19. B 50 mHz and the formula is:

$$\text{BW (sys)} = \frac{\text{BW (per km)}}{\text{Length (km)}} \qquad \text{BW (sys)} = \frac{250}{5}$$

20. True Lightwave links may be modulated digitally or in an analog fashion.

Chapter 27

1. True All devices, to be considered optical devices, must incorporate some basic optical principles or mechanisms.

2. True This is one technique of optical switching. Note that although electrical and electro-mechanical means for repositioning may be employed, the light energy is not directly controlled or routed by those electro-mechanical devices.

3. False A diffusion grating is etched or scored on an optical surface, and no prisms are involved in the basic process at all.

4. True Lenses, as a very basic optical mechanism, are often employed in optical devices.

5. False Mirrors, both plane and formed, are often incorporated into optical devices.

6. True Many optical devices such as couplers are fabricated from fused optical fibers.

7. False Lightwave systems, carrying signals at lightwave frequencies, cannot be directly tapped for RF signals, and the losses of lightwave systems generally prohibits lightwave tapping at many, random locations for subscriber service as well.

8. True For short lengths as indicators within a vehicle perhaps, and other special applications, optical fibers can and are fabricated from plastic or other materials.

9. False When we cable up several fibers, a primary concern is isolating each fiber from any mechanical stresses that the cabling process itself may present, or that the cable in place may introduce.

10. True This is the definition of macro-bending, and one reason for not carrying optical fibers around too small a radius.
11. False Almost always, regardless of usage, each optical fiber is individually protected with a coating, and in addition, in many applications, each fiber is encased in an individual buffering tube.
12. False Ribbon cable structures are expensive and elaborate, and are largely restricted to applications where the fiber count within a cable is rather large.
13. True Strength members are incorporated into cable structures to both add rigidity and strength to those structure.
14. False There are several means for joining fiber ends together, each with its own limitations or drawbacks, of course. There are mechanical splices that do not fuse fibers together. These cost less, and splicing costs are less too, but they may introduce some more loss than fusion splicing might. There are also reusable fiber connectors that allow disconnect and reconnect of fibers. These cost quite a bit, and they also introduce quite a bit of loss per connector, but they do provide some facility, especially at terminal locations. One must keep in mind that in many cases, the absolutely lowest splice loss is somewhat academic, and is not a primary concern, and the flexibility and ease of use of these other methods may make a lot of sense in some applications.
15. True During construction, extra cable must be temporarily stored on the ground. Laying this cable in a "figure eight" configuration, with due attention to the radius of all bends, is a practical and wide spread practice.
16. False There are no transmission considerations that mandate any metallic element in an optical cable structure. Cables that do not include any metallic element are called all-dielectric cables.
17. True By electrically bonding different plant together, the possibility of a difference in potential between the two is reduced or eliminated, and personnel and plant both are protected.
18. False With the proper practices and equipment, optical cable can certainly be plowed directly underground.
19. False Due to their light weight, flexibility, and small size, fiber cables can certainly be over lashed onto existing aerial cables.
20. True Since they are dielectric in nature, and carry lightwave frequencies well above any frequencies that might be induced into them, optical cables are immune to electromagnetic interference by induction.

Chapter 28

1. True We subdivide the service area into a number of nodes, and each node constitutes a small, stand alone distribution system. Since each node is served by an optical fiber, it follows that parallel fibers are necessary in hybrid systems of any appreciable size.
2. False Node size is determined by subscriber count, and the number of coaxial extensions is established to fill out this subscriber count within a node. Also, of course, it is not technically practical to split a single optical fiber, operating at lightwave frequencies, 10 or 15 times. The transmission losses would prohibit this.

3.	False	By dividing the subscribers across a number of technically separate and independent transmission nodes, the failure of any transmitter would only affect subscribers served by that node.
4.	False	Two way service on any optical link can be accomplished by using WDM on a single fiber, or by using a separate second fiber for the return transmissions alone.
5.	True	We can use a separate fiber for return transmissions from each node.
6.	True	WDM permits two-way transmissions on a single fiber, using different lightwave frequencies of course, just as we implement two-way transmission on a single cable in coaxial cable systems.
7.	False	The transmission performance of a lightwave transmitter is changed if the channels carried by that same transmitter are changed.
8.	True	This is one technique for accommodating various lengths in fiber links.
9.	True	This is another technique for accommodating various lengths in fiber links.
10.	False	Coaxial extensions are limited in length and in the number of RF amplifiers that may be serially connected. This determination or limitation may be different in different systems perhaps, and is established by the management and engineering departments of the individual cable operator.
11.	False	Fiber losses are always stated in dB, and specific signal levels, such as transmitter outputs or receiver inputs, are usually stated in dBm.
12.	False	Because they are mechanical devices, and the dimensions are very small, fiber connectors do introduce more transmission loss than other splicing techniques. Nevertheless, their disconnect and reconnect facility is attractive, and is usually provided at terminal ends or at terminal equipments.
13.	True	The overall performance of these two system elements is a combination of the two performances, and this is facilitated by using compatible terms to describe each element's performance alone.
14.	True	If the process given in this text is followed, all hybrid systems are much more predictable and easier to engineer. Variables like the number of active units required, such as RF amplifiers in coaxial systems for example, are reduced to a predictable few.
15.	False	Since fewer active devices are employed in hybrid systems, and the types and operational levels of devices is also reduced, the long term maintenance of hybrid systems is greatly reduced in complexity.
16.	True	Actually, since fewer active units are required, and failures or outages are restricted to small sections of a service area, the reliability of service in hybrid systems is much better than in all-coaxial systems.
17.	True	This is a good description of a hybrid system.
18.	False	In hybrid coaxial extensions, coaxial cable is used, and the selection of subscriber tap values is exactly the same as the process followed in all coaxial systems.
19.	True	A node is established to serve a number of subscribers. It is possible that the distribution of subscribers is such, in any particular system, that two receivers may be necessary to load up a particular lightwave transmitter and optical fiber with the correct number of subscribers to constitute a complete node.

20. False There are no inherent technical reasons to assume that, in a properly engineered hybrid system, transmission performance would always be poorer and, as a matter of fact, it is almost always better.

Chapter 29

1. True All routine maintenance tests are the best chance to look at the system over time, and should be considered as a "Quality Assurance" program also.
2. True Such tests verify that the system performance actually does meet all specifications such as C/N Ratio, CTB, etc., and many of these measurements are quite sophisticated. But routine maintenance tests can be largely addressed at maintaining system signal levels alone, a much simpler level of testing. If signal levels are maintained, one may reasonably expect that transmission performance is compliant and unchanged.
3. True Routine maintenance tests familiarize the personnel with the normal operation of the system at several points. Such familiarity prepares the personnel for rapid trouble identification, easy location, and proper restoration. It's also an excellent training or practice exercise for all personnel and establishes test uniformity and repeatability.
4. True Many Head End system test points are obscurely located and unidentified. Someone called out on an emergency, and less familiar with that Head End, or less qualified, can have trouble locating this test point, or knowing what normal levels at that point should be.
5. False Recording and reporting both the time of day and the temperature can be very important in analyzing some trouble condition at a future time. Reports should also be signed or initialed to impart some sense of responsibility and meaningful participation.
6. False The service personnel become quite familiar with their system and its normal operation, and this contributes to faster reaction and correction of outages or system abnormalities.
7. True All such test points are expected to be visited regularly, and should not expose any personnel or vehicles to risk during those visits. If tests at these points can be made inside the vehicle itself, this would also contribute to tests being made more thoroughly and repeatably, even in bad weather.
8. False This technique has been tested, and is practical and available. It may be particularly adaptable to the short cascades of RF amplifiers in hybrid systems.
9. True This is certainly true and self-evident.
10. False More sophisticated testing on a routine basis, however well done, or however experienced the people are, may often be completely unnecessary and may not contribute significantly to long term better quality of transmission.
11. True If complicated tests are to be conducted, using sophisticated equipments, the people doing such tests must be fully qualified or the tests themselves become valueless.
12. False Several such meters may be used in the same system, and each meter may be used to make system adjustments. Of course all meters should read the same, and all should be periodically calibrated to do so.
13. False Most lightwave receivers provide other test facilities to verify input light levels, and the uncertainty of properly restoring any fiber connection should be avoided in any routine, non - emergency measurements.
14. False Most standard tests used in all-coaxial cable systems do find direct applications in the long term maintenance and operation of hybrid systems.

15.	True	Although it is a common practice, it is unprofessional and technically incorrect. Signal levels are referenced as dBmV or, for lightwave links perhaps dBm, and the term dB, a ratio of two values, should be reserved for gain or loss only.
16.	True	When restoration involves the replacement of equipment, and adjustment of the new units is necessary, it must be carefully done by qualified people, or should be verified later by such people if necessary.
17.	False	These are legitimate customer complaints, and all such complaints should be considered and evaluated. This is, after all, a measurement of the quality of both your system and your service.
18.	True	All such reports must be evaluated. Even negative reports, if repeated, may have real value and merit.
19.	True	Quite obviously true and common sense as well.
20.	True	Although lightwave links may introduce a new technology, they do not automatically initiate or require a higher level of maintenance testing.

Chapter 30

1.	True	In most instances, terminal devices or equipment is located in the subscribers premises.
2.	True	This seems quit clear.
3.	True	At subscriber's premises, only the outer conductor must be grounded, and this is required by the National Electrical Code.
4.	False	Splitters and couplers are used, and are installed as required, but they do not pass AC power as the question states. In all other respects they function just as their counterparts do in conventional coaxial plant.
4.	False	Matching transformers are only required where the cable itself is at 75 Ohms charcteristic impedance, and the set to be served is at 300Ohms characteristic impedance.
6.	True	Active taps, in this case as compared to most taps, which are passive, require no operating power, and simply divert a predictable amount of RF energy to the service drop.
7.	True	This adequately describes dual cable systems and a common use of A-B Swutiches.
8.	True	This is the function and use of tunable converters.
9.	True	Grounding blocks do not provide electrical connection to the inner conductor, and it passes through, electrically that is, unaltered.
10.	True	Traps are usually off-premises and on the pole or in the pedestal, and one purpose is to inhibit or discourage subscriber tampering.
11.	True	When any RF carrier presented to the subscriber's set for use cannot be tuned by that set, then some RF conversion is certainly necessary.
12.	True	Some commercially available television sets do tune many non-standard broadcast television channels, and these may, and often do, coincide with the RF carriers on the cable system. Such sets are commonly called "cable ready".
13.	True	When a television signal is intentionally distorted or encoded to prevent unauthorized viewing of that picture, the term used is that the signal has been "scrambled".

14.	False	Addressability refers to the capability of a subscriber tap, or equipment at the subscriber's premises, to be individually addressed or pooled in turn from the system Head End. Digital addresses may be on a common carrier to all or many stations, but this one digital address is unique and individual for that station alone, and no other station would respond or react.
15.	True	Self-expanatory. Types of cable depend on size, and have different losses. Some stations many require less drop loss due to their length.
16.	False	All service drop cables can be supplied in a self-supporting structure.
17.	False	The standard, or most commonly employed fitting is called an "F" type fitting, and can be supplied in both male and female configurations.
18.	False	Such converters are usually plugged into a wall outlet and use subscrber-supplied operating power. None, to our knowledge, draw operating power from the cable system over the service drop.

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